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THE ROYAL AERONAUTICAL SOCIETY

JUNE 1961

CONTENTS

NOTICES

TRENDS IN AIRCRAFT PROPULSION — H. PEARSON

AIR TRAFFIC CONTROL—A Symposium

THE ROYAL AERONAUTICAL SOCIETY:
THE FIRST FIFTY YEARS—1869-1870 — J. LAURENCE PRITCHARD

TECHNICAL NOTES
Lower Bounds for Sonic Bangs—L. B. JONES. Reconnaissance Orbits Normal to the Ecliptic Plane—S. W. GREENWOOD.

THE BRANCHES

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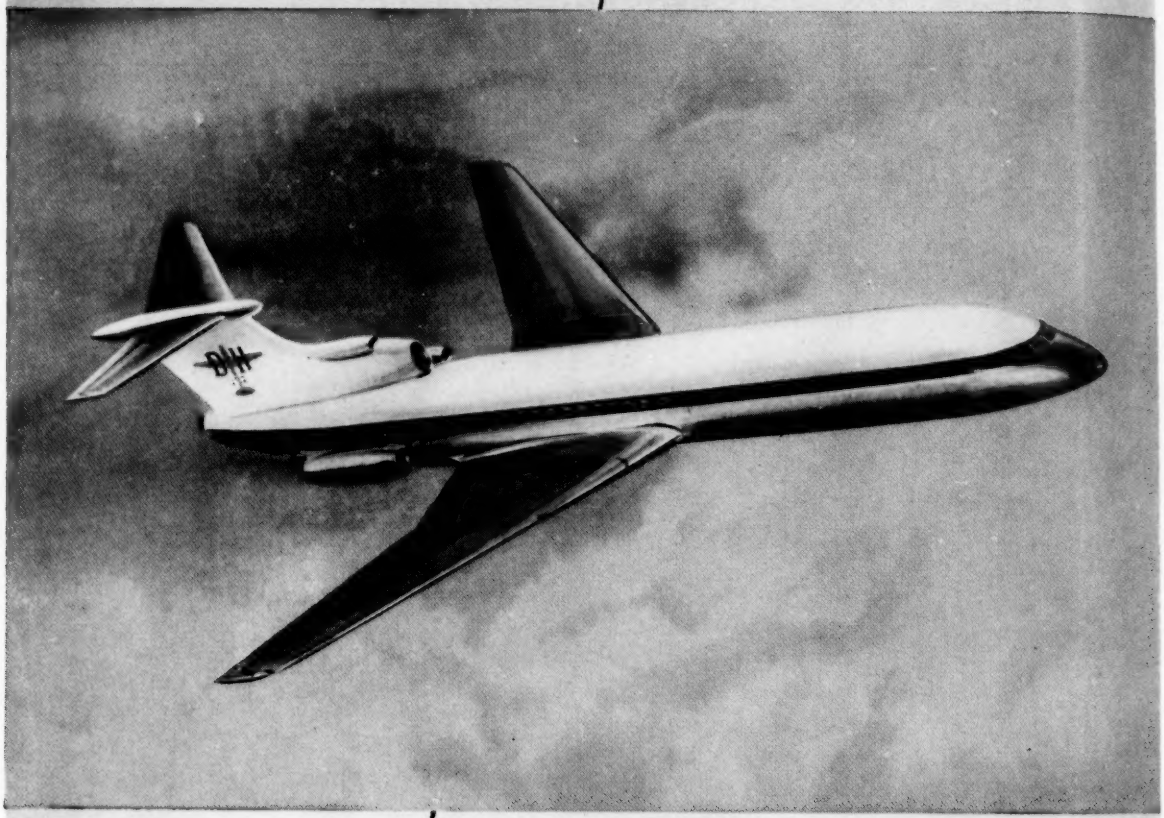

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VOLUME 65 JUNE 1961 NUMBER 606

CONTENTS

PAGE

Notices XXVII

President Takes Office—Newly-Elected Members of Council—Honorary Fellows—Honorary Companion—Supplement to the Oxford Dictionary—Presidential Chair for the Lecture Theatre—Medals, Awards and Prizes of the Society—Man Powered Flight: Canadian Reprints—Eighth Anglo-American Aeronautical Conference: Provisional Programme—National Aeronautical Laboratory, Bangalore—Elections—Symposium on "Some Aspects of the Physics of Space Research"—Southampton Seminar on Astronautics—News of Members.

Trends in Aircraft Propulsion — H. PEARSON — 373

Air Traffic Control—A Symposium 389

Responsibility of the State for Air Traffic Control — GROUP CAPT. J. B. VEAL
Responsibilities of the Individual Air Traffic Control Officer — ARNOLD FIELD
A.T.C. and the Civil Airline Operator — A. E. SLOCOMBE
Air Traffic Control and Military Operations — AIR CDRE. J. B. RUSSELL
The Application of Automatic Techniques to the Problem of A.T.C. — E. W. PIKE
F.A.A. Experience Gained in the Use of Digital Computation — J. L. ANAST
Secondary Surveillance Radar and Airborne Transponder System — G. G. ROBERTS
The Future of Air Traffic Control — CAPT. V. A. M. HUNT
Why Air Traffic Control?—Could an Air-to-Air Collision Avoidance System Radically Affect the Techniques of Air Traffic Control? — R. F. HANSFORD
The Influence of Aircraft Characteristics on A.T.C. Problems — B. N. TOMLINSON
V.T.O.L. and S.T.O.L. Aircraft and Helicopters and the System of Air Traffic Control They Will Require — J. K. B. ILLINGWORTH
Summary of Discussion — E. HANLEY and H. KEELING

The Royal Aeronautical Society: The First Fifty Years—1869-1870 — J. LAURENCE PRITCHARD — 429

Technical Notes 433

Lower Bounds for Sonic Bangs—L. B. JONES. Reconnaissance Orbits Normal to the Ecliptic Plane—S. W. GREENWOOD.

The Branches 438

Graduates' and Students' Section 439

The Library 440

REVIEWS: Testing Time—Fate is the Hunter—Studies of the History of Terms for Aircraft in English: (Two Volumes in the Gothenberg University Series)—Gas Turbines for Aircraft—Electrical Noise—An Introduction to Astrodynamics—Proceedings of the First International Agricultural Aviation Conference, 15th-18th September 1959—Impact: The Theory and Physical Behaviour of Colliding Solids—Embrittlement by Liquid Metals.
ADDITIONS TO THE LIBRARY REPORTS.

All communications for publication in the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., F.R.Ae.S., Hon.F.C.A.I., F.I.A.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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NOTICES

President of The Society 1961-1962

Air Marshal Sir Owen Jones, President of the Society for the year 1961-1962, took Office at the Annual General Meeting held on Thursday, 4th May 1961.

Council for 1961-1962

The following are the newly-elected Members of Council as a result of the Ballot declared at the Annual General Meeting held on Thursday, 4th May 1961.

*Professor J. A. J. Bennett
*Major G. P. Bulman
Mr. E. B. Dove
*Sir George Gardner
Mr. W. H. Stephens
Dr. E. W. Still
*Mr. T. A. Wolstenholme

*re-elected.

The complete list of Council for 1961-62, with the names of the President-Elect and the Vice-Presidents, will be published in the July JOURNAL.

Honorary Fellows

Honorary Fellowship, the highest honour the Society can confer has been awarded to the following:—

Sir Sydney Camm, C.B.E., F.R.Ae.S.,
Director and Chief Engineer, Hawker Aircraft Ltd., and a Past-President of the Society.

J. D. North, F.R.Ae.S.,
Chairman and Managing Director, Boulton Paul Aircraft Ltd.

Honorary Companion

Honorary Companionship has been awarded to—

J. N. Toothill, C.B.E.,
Director, Ferranti Ltd., Hollinwood, Lancashire and General Manager, Ferranti Ltd., Edinburgh.

Supplement to the Oxford English Dictionary

The following is the thirteenth list of aeronautical terms for the Supplement to the Oxford English Dictionary for which assistance in tracing earlier references is required. If members know of an earlier use than that given for any word in this list they are asked to write to the Editor, Oxford English Dictionary Supplement, 40 Walton Crescent, Oxford, giving the reference(s), date, author, title, chapter and page. Earlier lists have been published in alternate numbers of the JOURNAL since June 1959 and thanks are expressed to those who have already responded to these appeals.

gaggle, sb. (flight of aircraft)	1946	G. Gibson, *Enemy Coast Ahead*
glide path	1936	*Electrical Communication*, XV
glider-borne	1943	*Aeronautics*, February
glider train	1942	L. E. O. Charlton, *Britain at War*, I
gremlin (R.A.F. slang)	1942	*Observer*, 8th November
grid navigation	1944	*Geographical Review*, XXXIV
ground, v., grounding (of aircraft)	1940	*War Illustrated*, 5th January
ground control	1933	*Journal of the Royal Aeronautical Society*, XXXVII
ground control(led) approach (G.C.A.)	1945	*Newsweek*, 20th August
ground crew	1940	*Flight*, 7th November
ground marker (flare to mark target area)	1944	*Times*, 26th April
ground-to-air	1920	*Flight*, 10th June
ground-to-ground	1920	*Flight*, 10th June
guided missile	1945	*Newsweek*, 27th August
gun turret (in aircraft)	1919	A. Klemin, *Textbook of Aeronautical Engineering*

Presidential Chair for the Lecture Theatre

Sir Roy Fedden, M.B.E., D.Sc., Hon.F.R.Ae.S., Hon.F.I.A.S., President of the Society from 1938-1940 and again from 1944-45, has presented to the Society a Presidential Chair for the Lecture Theatre. The presentation was made on 18th May to Dr. E. S. Moult, C.B.E., B.Sc.,(Eng.), F.R.Ae.S., Immediate Past-President of the Society (in whose term of office the Lecture Theatre was opened). The presentation preceded the lecture to the Astronautics and Guided Flight Section by Mr. R. Smelt, F.R.Ae.S.

The Presidential Chair, which has been specially designed, is of teak with blue leather, handsomely tooled in gold and is representative of flight from the days of Montgolfier to the Sputnik. The following is the legend of the Chair:—

Leather Embossings (reading downwards):—First artificial earth satellite in orbit, launched by the U.S.S.R. on 4th October 1957; Orville and Wilbur Wright Aeroplane. First powered and controlled flight by Orville Wright, 17th December 1903, Kittyhawk, U.S.A.; Lilienthal Glider. First controlled monoplane glider flight. By Otto Lilienthal, Germany, 1895; Cayley model glider. First successful aeroplane of modern configuration made and flown by Sir George Cayley, Yorkshire, 1804.

On Seat Cushion:—Montgolfier Hot Air Balloon. First aerial voyage by man, flown by De Rozier and D'Arlandes, France, 21st November 1783.

Carvings:—*Under Right-hand Armrest*—Vickers Vimy first non-stop North Atlantic easterly aeroplane flight, Alcock and Brown, U.K., 15th June 1919. *Under Left-hand Armrest*—R.34 Airship first westerly non-stop crossing and first double crossing of North Atlantic, U.K., July 1919.

Medals, Awards and Prizes of the Society

The Medals, Awards and Prizes conferred by the Council this year are as follows; with the Scrolls of Honorary Fellowship and Honorary Companionship they will be presented at the Wilbur Wright Memorial Lecture. Normally given in May, the Lecture will be given this year on 12th September during the Anglo-American Conference.

The Society's Silver Medal—awarded for work of an outstanding nature in Aeronautics—to

R. Hafner, F.R.Ae.S.,

Technical Director (Research), Westland Aircraft Ltd., "for his outstanding work in the design and development of rotary wing aircraft."

The Society's Bronze Medal—awarded for work leading to an advance in Aeronautics—to

L. Haworth, O.B.E., B.Sc., F.R.Ae.S., M.I.Mech.E.,
Assistant Chief Engineer,
Propeller Turbines, Rolls-Royce Ltd.,

"for his work leading to advances in aircraft gas turbine design."

The British Gold Medal for Aeronautics—awarded for outstanding achievement leading to advancement in Aeronautics—to

Dr. S. G. Hooker, O.B.E., B.Sc., A.R.C.Sc., D.I.C., F.R.Ae.S., M.I.Mech.E.,

Technical Director (Aero), Bristol Siddeley Engines Ltd., "for his outstanding practical achievement in aero-engine design and development."

The British Silver Medal for Aeronautics—awarded for practical achievement leading to advancement in Aeronautics—to Pierre Satre,

Technical Director, Sud-Aviation, Paris,

"for his practical achievement in aircraft design, with special reference to his development of the rear-engined configuration."

The Wakefield Gold Medal—awarded for contributions towards Safety in Aviation—to

Dr. E. Eastwood,
Director of Research,
Marconi's Wireless Telegraph Co., Ltd.,

"for his contributions towards safety by the development of air traffic control and navigational aids."

The R. P. Alston Medal—awarded for practical achievement associated with the Flight Testing of Aircraft—to

R. P. Dickinson, B.Sc.(Eng.), A.F.R.Ae.S.,
Superintendent, Aeroplane and Armament Experimental Establishment, Boscombe Down,

"for his practical achievement in the execution and direction of flight test observation work."

The N. E. Rowe Medals—for younger members of the Society, and awarded for the best lecture given before any Branch of the Society by a member of a Branch—for two age groups, (*i*) 21 to 26 years of age and (*ii*) under 21 years of age—to J. Wilding of the Chester Branch.
for his paper "Bird Flight and the Aeroplane." (21-26 years) —to W. Bishop, of the Brough Branch,
for his paper "The Development of Tailless Aircraft and Flying Wings." (Under 21 years of age).

The Alan Marsh Medal—awarded to a British pilot in recognition of outstanding helicopter pilotage achievement—to Jack Brannon,

a pilot with Bristow Helicopters Ltd.,

"for his evacuation of an injured oil-man from the offshore drilling rig, de Long 144, to Abadan Hospital during the night of the 26th January 1960."

The Alan Marsh Award—awarded to a British student who has shown exceptional ability in technical study in the rotary wing field—to

M. S. Eden,

a former apprentice at Saunders-Roe Ltd., at present at the College of Aeronautics.

Note: The Alan Marsh Medal and Award were founded by the Helicopter Association of Great Britain (now the Rotorcraft Section of the Society) in 1955 to commemorate the work of Alan Marsh.

The following Medals and Prizes of the Society awarded by the Council for papers published in 1960 were presented by the retiring President, Dr. E. S. Moult, C.B.E., B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E., at the Annual General Meeting on 4th May 1961:—

The Simms Gold Medal—for the most valuable contribution on any subject allied to aeronautics—to

Professor D. B. Spalding,
M.A., Ph.D., A.M.I.Mech.E., A.M.Inst.F.
(Professor of Heat Transfer at Imperial College of Science and Technology),

for his paper "Heat and Mass Transfer in Aeronautical Engineering." (May 1960 Quarterly.)

The George Taylor (Australia) Gold Medal—awarded for the most valuable paper on Aircraft Design, Manufacture, or Operation—to

A. J. Troughton, M.A.(Cantab.), A.F.R.Ae.S.
(Chief Structural and Mechanical Engineer,
Sir W. G. Armstrong Whitworth Aircraft Ltd.),

for his paper "Relationship Between Theory and Practice in Aircraft Structural Problems." (November 1960 Journal.)

The Edward Busk Memorial Prize—awarded for the most valuable contribution on Applied Aerodynamics—to

C. Bourque, M.Sc., and
Professor B. G. Newman,
Ph.D.(Sydney), M.A.(Cantab.), A.F.R.Ae.S.,
(Professor of Aerodynamics, McGill University),

for their paper "Reattachment of a Two-Dimensional, Incompressible Jet to an Adjacent Flat Plate." (August 1960, The Aeronautical Quarterly.)

The Orville Wright Prize—awarded for the most valuable contribution to The Aeronautical Quarterly on some subject of a technical nature in connection with Aeronautics—to

Professor W. H. Wittrick,
Ph.D., M.A., A.F.R.Ae.S., M.I.A.S.
(Professor of Aeronautics, University of Sydney),

for his paper "Analysis of Stress Concentrations at Reinforced Holes in Infinite Sheets." (August 1960 Quarterly.)

The Herbert Akroyd Stuart Memorial Prize—awarded for the most valuable paper on Aircraft Propulsion—to

J. S. Alford,
B.S.M.E., A.F.R.Ae.S., A.S.M.E., S.A.E.
(Designing Engineer, Large Jet Engine Department, General Electric Company, Cincinnati),

for his paper "Power Plants for Supersonic Transports." (October 1960 Journal.)

The Branch Prize—awarded for the best paper on an aeronautical subject read before the Branches of the Society, and published in the Society's publications—to

Lt. Cdr. D. J. Whitehead,
A.F.C., A.R.Ae.S., R.N.(Retd.),
(Chief Test Pilot, Blackburn Aircraft Ltd.),

for his paper "The Low Speed Approach and Catapult Launch Problems in High Performance Naval Aircraft." (April 1960 Journal.)

The Usborne Memorial Prize—awarded for the best paper written by a Graduate or Student on some subject of a technical nature connected with Aeronautics—to

T. W. F. Moore, B.Sc., M.Sc., Grad.R.Ae.S.
(Guided Weapons Department, Bristol Aircraft Ltd.),

for his paper "Some Experiments on the Reattachment of a Laminar Boundary Layer Separating from a Rearward Facing Step on a Flat Plate Aerofoil." (November 1960 Journal.)

Man Powered Flight—Canadian Reprints

In response to requests, the Society has ordered from the Canadian Aeronautical Institute 100 reprints of the paper "Man-Powered Flight in 1935-37 and Today" by Helmut Haessler and 100 reprints of the paper "Man-Powered Flight—A Myth or Reality" by W. Czerwinski, which were published in the March 1961 and April 1961 issues of *The Canadian Aeronautical Journal*. It is hoped that these will be available soon at 5s. each, post free.

Dr. E. S. Moult, the retiring President, receiving from Air Marshal Sir Owen Jones, President 1961-62, a shield bearing the Society's crest and recording his term of office.

Eighth Anglo-American Aeronautical Conference
London, 3rd-14th September 1961

The Eighth Anglo-American Aeronautical Conference, convened by the Society and by the Institute of the Aerospace Sciences and the Canadian Aeronautical Institute, will be held in London at 4 Hamilton Place from 3rd-14th September 1961. All members of the Society should have received with their May JOURNAL an application form for registration. Only members of the Royal Aeronautical Society, the Institute of the Aerospace Sciences and of the Canadian Aeronautical Institute may attend the Conference. The registration fee is £10 which will entitle members to attend lectures, to receive preprints of the 15 papers and to receive the final Conference Proceedings. The registration fee does not cover attendance at the social functions. On registering members will receive a questionnaire with details of the social functions.

The closing date for registration is 31*st July* 1961.

A special programme of visits and entertainment is being arranged for ladies accompanying the American and Canadian delegates; it is hoped that ladies accompanying British delegates to the Conference will also take part in this programme.

The following is the provisional Conference programme:

Sunday 3rd September

Reception and registration for all delegates at 4 Hamilton Place. 7.0 p.m. - 9.30 p.m.

Monday 4th - Friday 8th September

American and Canadian delegates visit firms in the British Aircraft Industry, Government Establishments and the S.B.A.C. Show at Farnborough.

Technical Sessions—in the Lecture Theatre, 4 Hamilton Place.

Monday 11th September

9 a.m. - 10.30 a.m.	Meteorological Measurements from the Tiros Satellite—William G. Stroud (*N.A.S.A.*).
11 a.m. - 12.30 p.m.	Some Aspects of Satellite Control and Stabilisation—E. G. C. Burt (*Royal Aircraft Establishment*).
2 p.m. - 3.30 p.m.	Upper Atmosphere Experiments with Particular Reference to Black Knight and Skylark—Sir Harrie Massey (*University College, London*).
4 p.m. - 5.30 p.m.	Advancement in Spacecraft Technology—George Mueller (*Space Technology Laboratories*).

Tuesday 12th September

9 a.m. - 10.30 a.m.	Ground Proximity Effects Associated with V/STOL Aircraft—John P. Campbell (*Langley Research Center, N.A.S.A.*).
11 a.m. - 12.30 p.m.	Considerations in Selecting VTOL Propulsion Systems—A. P. Adamson and D. Cochran (*General Electric Co.*).
2 p.m. - 3.30 p.m.	The Inverted Turbo-Jet—Dean D. L. Mordell, A. V. Svreenath and F. W. Eyre (*McGill University*).
4 p.m. - 5.30 p.m.	Aerodynamics and Propulsion Considerations of Minimum-Field Aircraft, P. L. Sutcliffe and V. K. Merrick (*Hawker Siddeley Aviation Ltd.*); and A. R. Howell (*National Gas Turbine Establishment*).
Evening, 7 p.m.	49th Wilbur Wright Memorial Lecture. Researches in Space Flight Technology—Dr. Abe Silverstein (*N.A.S.A.*).

Wednesday 13th September

9 a.m. - 10.15 a.m.	The Transports of the Future—A Systems Approach — Harold D. Hoekstra and George Prill (*Federal Aviation Agency*).
10.30 a.m.-11.45 a.m.	The Influence of Some Operational Problems on Supersonic Air Transport—R. G. Thorne (*Royal Aircraft Establishment*).
11.45 a.m.-1.00 p.m.	The Supersonic Commercial Air Transport—John Stack (*Langley Research Center*).
Afternoon	River Trip for All Delegates and Wives.

Thursday 14th September

9 a.m. - 10.30 a.m.	Looking Ahead in V/STOL—George S. Schairer (*The Boeing Company*) and Lee L. Douglas (*Vertol*).
11 a.m. - 12.30 p.m.	General Aspects and Implications of Supersonic Transport Aircraft—Dr. A. E. Russell (*Bristol Aircraft Ltd.*).
2 p.m. - 3.30 p.m.	Control of V.T.O.L. Aircraft—J. J. Foody (*Short Bros. & Harland Ltd.*)
4 p.m. - 5.30 p.m.	The Nature of Aerofoil Characteristics with a Sink Located in the Upper Surface (Comparison of Theory with some Fan-in-Wing Experiments)—D. C. Whittley and J. R. Bissell (*Avro Aircraft Ltd., Ontario*).
5.30 p.m. - 6.00 p.m.	Concluding remarks by the three Presidents.

The Conference Dinner/Dance—at the Dorchester.

The National Aeronautical Laboratory, Bangalore

The National Aeronautical Laboratory of the Council of Scientific and Industrial Research are holding a Seminar on Aeronautical Sciences at Bangalore in November 1961. It is proposed to hold sessions on the following subjects:—

(1) Fluid Mechanics, (2) Aerodynamics, (3) Wind Tunnel Design, (4) Aircraft Structures and Materials, (5) Aircraft Propulsion, (6) Aviation Electronics, (7) Aviation Meteorology.

The exact date of the Seminar has not yet been indicated, but those who are interested should write to:—Dr. P. Nilakantan, Director, National Aeronautical Laboratory, Jayamahal Road, Bangalore, 1.

Elections

The following is a list of elections and transfers of membership of the Society:—

Associate Fellows

Albert Frederick William Anderson
Lawrence Harry Andrews
Stanley Herbert Bates
John Edmund Birks
Ambrose Leo Cresswell (*from Associate*)
Jeremy Patrick Bourne Cuffe (*from Graduate*)
Anthony Stephen Delahunty
Robert Fergus Dunlop
Edward Fiddler (*from Graduate*)
Ian James Ford (*from Associate*)
John David Gabbott (*from Graduate*)
William George Jones
Patrick Joseph McMahon (*from Graduate*)
James Insley Osborne (*ex Graduate*)
Geoffrey John Purdue
Soli Kaikhushroo Sahiar (*from Graduate*)
Ivor Harold Smart (*from Graduate*)
Edward Lennard Stokes
Peter Hubert Swift (*from Graduate*)
Cornelius Gregorius Van Niekerk
Reginald Dennis Waddingham (*from Associate*)

Associates

Harry Michael Archer
Harold Everard Cederman
Richard John Chandler
Bernard C. Maranda (*from Student*)
John Marsh
Victor Beresford Nightscale
William John Victor Surrage

Graduates

Brian Douglas Bergquist
John Patrick Billingham (*from Student*)
Peter Gerald Boid (*from Student*)
Robert Henry Burrin (*from Student*)
John Russell Catford (*from Student*)
Ian William Roger Exwood
Geoffrey Edward Faragher
John Duncan Harrison (*from Student*)
Paul Barnard Hirst
Julian Howard
Janet Elizabeth Howard
Christopher Ian Johnson
Thomas Francis Kean
John Gordon Jervis Lee
John William Lowther (*from Student*)
Derek Gordon MacWilkinson (*from Student*)
John Vincent Maude (*from Student*)
Roger Neve
James Wyllie Pattison
Codrington Theodore Proctor
Anthony John Weybourne Reeves
Bernard Renyard
Vellara Varghese Samuel (*from Student*)
Alfred John Ward Smith (*from Student*)
Robert Anthony Streather
Paul Thompson (*from Student*)
Ronald Gordon Thory
John Charles Tipping

Students

Wilfred Bishop
Yves Caubet
Alan David Davies
John Howard Glover
William Hodge Gracie
Rodney Stuart Hadwen
Brian Laurence Hayes
Ove William Hoiby
Aubrey Leonard Hood
Robert William Jagger
Christine Frances Jones
William Edward Jones
Derick Anthony Martin
Charles Peter Smith
Kenneth Christopher David Watkin

Companions

Genefer Margaret Boxall
Fong Hoi

Symposium on "Some Aspects of the Physics of Space Research"

The Institute of Physics and The Physical Society will hold a residential Symposium on *Some aspects of the physics of space research* at the Royal Military College of Science, Shrivenham, Swindon, Wiltshire, from 20th-22nd September 1961. The subjects to be discussed are: the advantages to physicists of space research; cosmic rays, particle physics and meteorology; physical techniques in space research; and rockets, orbits and trajectories. Further details may be obtained from the Administration Assistant, The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1.

Seminar on Astronautics

A seminar on Astronautics, jointly sponsored by the Department of Aeronautics and Astronautics, University of Southampton, and A.G.A.R.D., will be held at the University from 12th-19th July 1961. E. T. Jones, C.B., O.B.E., M.Eng., F.R.Ae.S., Vice-Chairman, A.G.A.R.D., will open the seminar and the following papers will be given:—

Introductory Lecture, M. J. Lighthill, F.R.S., Director, Royal Aircraft Establishment; Orbits in the Solar System, Dr. J. G. Porter, Royal Greenwich Observatory; Space Navigation, Capt. P. V. H. Weems, U.S. Naval Academy; Earth Satellite Orbits, D. G. King-Hele, G.W. Department, R.A.E.; Re-Entry Orbits, T. R. F. Nonweiler, The Queen's University of Belfast; Physical Properties of the Upper Atmosphere, Prof. E. Vassy, University of Paris; Hypersonic Aerodynamics, K. N. C. Bray, University of Southampton; Low Density Test Facilities, Prof. R. L. Chuan, Director, Engineering Center, University of Southern California; Physiological Limitations of Man in Space, Flt.-Lt. J. C. Guignard, R.A.F. Institute of Aviation Medicine; Operation and Control of Rocket Engines, S. L. Bragg, Chief Scientist Rolls-Royce Ltd.; Advanced Air-breathing Engines, Dr. R. R. Jamison, Assistant Chief Engineer, Bristol Siddeley Engines Ltd.; Noise Problems at Launch and Re-Entry, Prof. E. J. Richards, University of Southampton; Some Design Problems of Thin Shell Structures, D. J. Johns, College of Aeronautics; Optimisation of Space Vehicles and Launchers Relative to their Missions, Prof. Fraeijs de Veubeke, University of Liege; A Method for Solving Non-Linear Thermal Problems in Re-Entry of Space Vehicles, Prof. L. Broglio, University of Rome; Materials for Space Vehicles, Prof. A. J. Murphy, Principal, The College of Aeronautics; Evening: Space Flight Projects Based on Blue Streak, G. K. C. Pardoe, Chief Weapons Research Engineer, de Havilland Aircraft Co. Ltd.; Problems of Long Range Detection and Tracking, Dr. E. V. D. Glazier, Head of Ground Radar Dept., Royal Radar Establishment, Malvern; Problems of Guidance in Astronautics, Dr. A. W. Lines, G.W. Department, Royal Aircraft Establishment; and Recent Advances in the Theory of Automatic Control, Dr. J. K. Lubbock, University of Cambridge.

Full details and application forms may be obtained from the Organising Secretary, Dr. B. L. Clarkson, Department of Aeronautics and Astronautics, University of Southampton. Tel. 54071.

News of Members

Air Commodore F. R. Banks (*Fellow*), Managing Director, Blackburn Engines Ltd., has been appointed Chairman of the Board of the A.T.S. Co. Ltd.

A. D. Baxter (*Fellow*) formerly Director and Chief Executive, Rockets and Nuclear Power, de Havilland Engine Co. Ltd., is now Executive Director (Engineering).

J. S. Bell (*Associate Fellow*) formerly with Fairey Aviation Co., of Australia Pty. Ltd., is now Experimental Officer, Weapons Research Establishment, Salisbury.

E. L. Beverley (*Associate*), Sales Manager (Guided Weapons), British Aircraft Corporation, has been appointed a Vice-President of British Aircraft Corporation (U.S.A.) Inc.

Wing Cdr. D. L. R. Bird (*Associate Fellow*) formerly at A. & A.E.E., Boscombe Down, has been posted to the British Defence Staff, Washington.

Viscount Caldecote (*Associate Fellow*) has been appointed a Director of British Aircraft Corporation (Australia) Pty., Ltd.

C. Clarkson (*Associate Fellow*), North American representative of Vickers-Armstrongs (Aircraft) Ltd., has been appointed President of British Aircraft Corporation (U.S.A.) Inc.

Sir Harold Roxbee Cox (*Fellow*), Chairman of the Metal Box Company Ltd., has been appointed Chairman of the Council for Scientific and Industrial Research.

The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

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Trends in Aircraft Propulsion

BY

H. PEARSON

(Chief Engineer (Performance and Research) Rolls-Royce Ltd.)

The 1,186th Lecture to be given before the Society—and the 40th Main Lecture to be held at a Branch centre—"Trends in Aircraft Propulsion" by H. Pearson, B.A., F.R.Ae.S., Chief Engineer (Performance & Research), Rolls-Royce Ltd., was given under the auspices of the Southampton Branch on 19th January 1961. Professor A. R. Collar, M.A., D.Sc., F.R.Ae.S., F.I.A.S., Vice-President of the Society, presided. A message specially recorded on tape by the President, Dr. E. S. Moult, C.B.E., B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E., was broadcast. The President said how much he regretted missing Mr. Pearson's lecture and the meeting at the Southampton Branch. He had looked forward to the occasion but he and Dr. Ballantyne, Secretary of the Society, were attending an international congress in Detroit. He was grateful to Professor Collar for deputising for him and sent his best wishes to the Southampton Branch and to everyone present on the occasion.

Professor Collar, introducing the Lecturer, said that Mr. Pearson graduated in Physics from Christ Church, Oxford, and since 1940 he had been with Rolls-Royce, working first at Hucknall on problems connected with exhaust systems. In 1943 he had joined the Rolls-Royce team at Barnoldswick under Dr. S. G. Hooker, now of Bristol Siddeley Engines Ltd. Mr. Pearson had returned to Derby in 1946 as Chief Performance Engineer on turbine engines and three years later was appointed Chief Research Engineer. He was now a Director of the Aero Division of Rolls-Royce, and Chief Engineer (Performance and Research).

1. Introduction

As this lecture is meant to deal with "trends" and not the "future of" aircraft propulsion I shall avoid any great predictions for the future and the reader will be spared any attractive (or agonising) glimpses of fare-paying passengers propelled by plasma jets, nuclear engines or rockets, in descending order of improbability. Instead I have set myself the quite humdrum task of explaining present tendencies in propulsion power plants, the reasons for such tendencies and whether any significant changes can be expected to occur in the *near* future. To give precision to what might otherwise be a vague general statement I have attempted to forecast the performance and weight improvements for certain types of engine that could result in the next few years from present trends and possibilities. The word "could" is used here very intentionally because not all the various engines will be developed with equal urgency, and between "possible performance" and its achievement in a marketable engine there is a wide gulf of some £10–20 millions, to enforce another form of realism into our predictions.

Not all different types of power plant will progress, or have progressed, equally rapidly due to a variety of circumstances that will be enlarged upon later. Nevertheless, for the aircraft designer planning new projects some performance predictions for the different types, on the same technical basis of optimism, irrespective of production likelihood, should be available, so that the feasibility of different aircraft types may be correctly compared. These predictions should normally be at something like five-seven years ahead, that is at the service date of a brand new project, or perhaps the performance achievable two years after service introduction.

1.1 AIRCRAFT TYPES

I propose to deal with the following aircraft types:

(1) Subsonic Jets
(2) Propeller Turbines
(3) Supersonic Transports
(4) V.T.O.L. Aircraft (S.T.O.L.?)
(5) Military Aircraft.

I must apologise for putting Military Aircraft at the bottom of this list and lumping all such types together. There are several reasons for this. First, due to the varying operational conditions of such aircraft it is usually more difficult to specify the engine requirements and type with the same distinctness as for civil aircraft; secondly, requirements of security prevent the putting down of precise figures, and thirdly, because we seem to be entering a period when it is questionable whether a new engine type will be financed for military purposes, but rather it will have to be an adaptation of an existing or proposed civil engine.

2. Subsonic Jet Aircraft

We are already well into the first generation of subsonic civil jet aircraft; the Boeing 707 and Douglas DC-8 representing the long range type while the Comet, Convair 880 and Caravelle represent the middle and shorter range applications. A new short-medium range aircraft, the de Havilland 121, is under construction and it is understood that Boeing intend to build their 727 of

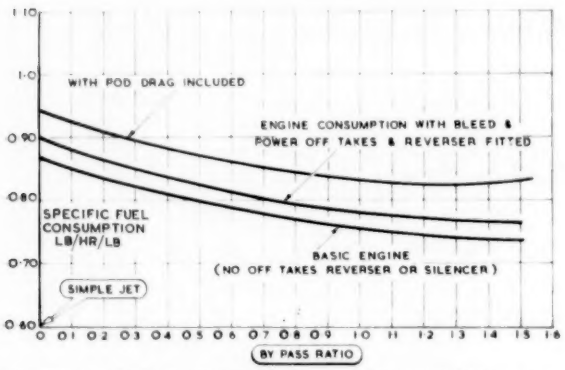
WITH POD DRAG INCLUDED
ENGINE CONSUMPTION WITH BLEED & POWER OFF TAKES & REVERSER FITTED
SPECIFIC FUEL CONSUMPTION LB/HR/LB
BASIC ENGINE (NO OFF TAKES REVERSER OR SILENCER)
SIMPLE JET
BY PASS RATIO

FIGURE 1. Specific fuel consumption cruise at 35,000 ft. at a Mach number of 0·8 I.S.A.

somewhat similar type. Of the existing types, there are also improved versions on offer with improved performance, substantially deriving from improved power plants.

2.1 BY-PASS ENGINES

This period is of especial interest because it appears to have resolved one technical argument fairly conclusively, the question of by-pass engines. At the beginning of the period there was one by-pass engine available, the Rolls-Royce Conway, but a range of straight jet engines. If this lecture were being given three years earlier, I should have had to go through the arguments of explaining the by-pass principle in some detail and just why my Company considered it superior to the straight jet engine for subsonic jet aircraft. Now, however, the picture is so different that I am rather put in the position of explaining why we think that very high by-pass ratios are not the best solution. I wish I could say that this reversal has been brought about by the superior sales record of the Conway over its main competitor, but in reality other factors have intervened to influence the general "climate" of opinion. First, it has been found in America that conversion of existing engines to "fan" engines was a fairly economical method of increasing the thrust of these engines, particularly for take-off where existing aircraft were especially deficient,

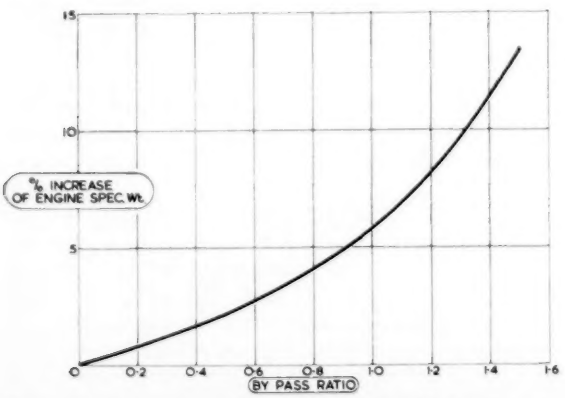

FIGURE 2. Increase in engine specific weight with by-pass ratio.

and secondly, the rapid emergence of take-off noise as an annoyance to airport communities acted as a strong catalyst in favour of the by-pass engine. Almost overnight, from competing against the straight jet, the By-pass Engine was faced with competition from Fan Engines of a "High" by-pass ratio of something like 1·5. While admiring the speed with which these conversions of both faith and hardware were carried out, we have taken leave to doubt their correctness.

The best value of by-pass ratio undoubtedly depends upon many factors, in particular the aircraft range and speed, and installation requirements, but in addition, on the engine thermodynamics. We have always been of the opinion that at current values of operating temperature the optimum ratio lay in the region between about 0·6 and unity. Take-off noise is improved at higher ratios and this is one of the main reasons why, in our latest engines, we have used the upper value of this range. Our reluctance to go further was due to two reasons, first, that we believed a steeply rising economic penalty was involved in by-pass ratios substantially higher than unity, and secondly, that such engines would give a higher landing noise. This point will be referred to later in this section.

Figure 1 shows, for a typical cruise condition and a fixed value of engine compression ratio and combustion temperature, the specific fuel consumption plotted against by-pass ratio. This shows a gradual diminution in the basic value as by-pass increases, but above unity the improvement is very small. When the various power offtakes, bleed and thrust reverser requirements that are necessary for a modern aircraft are considered, this improvement is reduced. For a given thrust, higher by-pass ratio almost inevitably means a larger engine diameter and therefore an increased "pod" drag and allowance for this in the top curve shows that on "installed" specific fuel consumption alone, 1·2 is the maximum by-pass ratio that should be used, while the gain from going above unity is negligible.

Figure 2 indicates the power plant weight variation with by-pass ratio and shows how this tends to increase

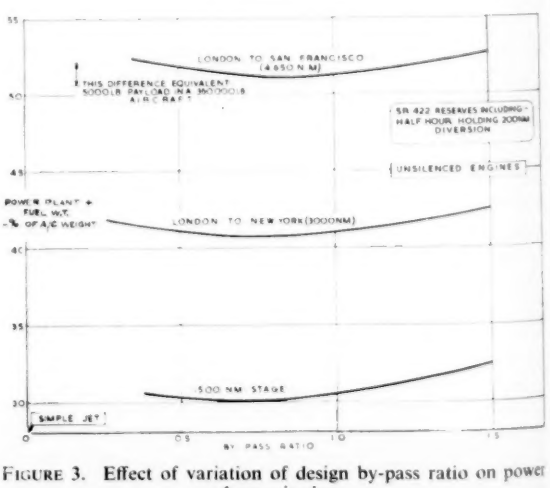
LONDON TO SAN FRANCISCO (4850 N.M.)
THIS DIFFERENCE EQUIVALENT 50001B PAYLOAD IN A 350TON/LB A/C RAFT
SR 422 RESERVES INCLUDING HALF HOUR HOLDING 200NM DIVERSION
UNSILENCED ENGINES
POWER PLANT + FUEL WT. % OF A/C WEIGHT
LONDON TO NEW YORK (3000NM)
500 NM STAGE
SIMPLE JET
BY PASS RATIO

FIGURE 3. Effect of variation of design by-pass ratio on power plant criterion.

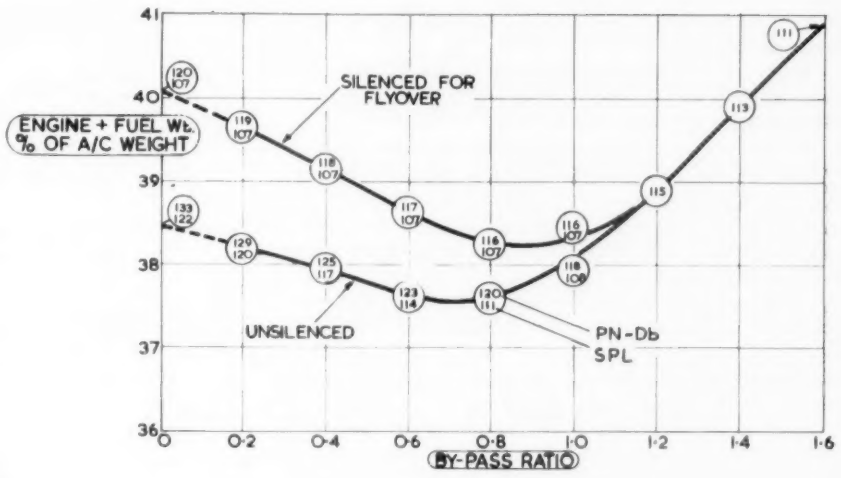

FIGURE 4. By-Pass optimisation study engine+Fuel weight for 1,500 n.m.

rather rapidly above about 0·6. The result of this is to force the optimum values down well below unity. Fig. 3 shows the effect of these on Power Plant plus fuel weight against by-pass ratio for three ranges, 1,500 n.m., 3,000 n.m. (London-New York) and 4,650 n.m. (London-San Francisco). The effect of increased range is hardly noticeable, a value of about 0·8 by-pass ratio being near the optimum in all cases. The penalty in using engines of high by-pass ratio (1·5) is of the order of 3½ per cent aircraft weight; since, however, the payload of a long-range aircraft is only about 12 per cent, this is a substantial penalty.

The foregoing considerations take no account of take-off noise levels. With higher by-pass ratios the jet velocities are reduced and so less jet noise is developed. To compare engines on a basis of take-off noise levels is rather complex due to the following:

(*a*) Noise level over a community is mainly a function of aircraft height and thus of the actual take-off thrust provided.

(*b*) High by-pass engines for a given cruise requirement will, in general, have a higher take-off and initial climb thrust than low ratio engines—indeed it is possible that a straight jet engine of the correct thrust size for cruise might not be able to meet the airport take-off requirements.

(*c*) Noise levels are also critically dependent on noise abatement flying techniques after initial climb.

As an example, therefore, of the problem, it is better to consider a specific case where a given cruise requirement has to be met, and also a given take-off is required. This means that for the low by-pass engines, take-off is achieved as a design requirement and the cruise condition will be somewhat throttled back (with gains in operating life perhaps, not taken into consideration here) while for high by-pass engines, the cruise becomes the design requirement, take-off being a relatively easier condition.

Figure 4 shows the results of one such study. In this case all engines were silenced to a common required noise level, although at the high by-pass end the actual jet noise was somewhat better than the requirement (*i.e.* above 1·2 ratio). If a reduced noise level were aimed at it would favour a little more those higher ratios but, as explained later, the noise would then be largely governed by other sources than the jet noise.

Practical weight and performance losses for silencing have been incorporated in these calculations, as well as all the effects of engine size and weight on aircraft installation. It will be seen that the best value of by-pass ratio is again about 0·8. This is for quite a short range of 1,000 miles, but at 1,500 miles the results are little different.

The results of the previous study illustrate that although low take-off jet noise is achievable by high by-pass ratio, it is only at the expense of a large economic penalty. It is now known, however, that this reduction of jet noise will, to a large degree, have been fruitless because the levels of compressor noise and other noise emanating from the engine will have become the dominating sources. The former will, for given compressor design technique, have been increased by raising the by-pass ratio because of the greater total mass flow of air or cross section of compressor, while for the latter, although probably insufficient is yet known as to the laws governing its

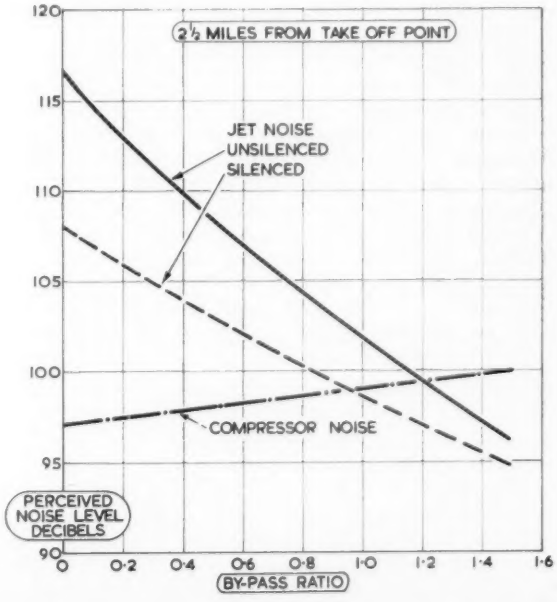

FIGURE 5. Typical noise of medium range jet aircraft.

production for accurate forecasts, it is unlikely to have been reduced.

Figure 5 illustrates the noise levels due to these two latter sources and shows that again little is achieved in raising the by-pass ratio above unity.

For all the foregoing reasons we consider that at present operating temperatures and aircraft speeds, by-pass ratios above about unity are not desirable. It should be emphasised, however, that as operating temperatures are increased it becomes more worth while to use somewhat higher by-pass ratios.

As combustion temperatures are raised the jet velocities are increased with detriment to both propulsive efficiency and jet noise. Use of a higher by-pass ratio will tend to rectify this situation without reducing the thrust output per unit weight, or per unit frontal area compared with present engines. It would therefore probably be more sensible to think in terms of specific thrust level, *i.e.* thrust per unit air mass flow, than in values of by-pass ratio. For a given specific thrust, noise output and propulsive efficiency will remain constant. It seems to me that these specific thrust values will tend to remain constant in the next few years. This point will be referred to again under "Combustion Temperature."

2.2 PRESSURE RATIO

By-pass Ratio is only one parameter of an engine; there are many others which are gradually changing with research and development. Fig. 6 shows the gradual increase of pressure ratio with date that has occurred. It is an interesting speculation as to whether it will increase further.

Figure 7 shows for a particular cruise combustion temperature the effect on specific fuel consumption and engine weight of increase of compressor temperature rise or pressure ratio. Naturally the former diminishes but the latter, due to extra numbers of compressor and turbine stages, tends to increase. Now the relative

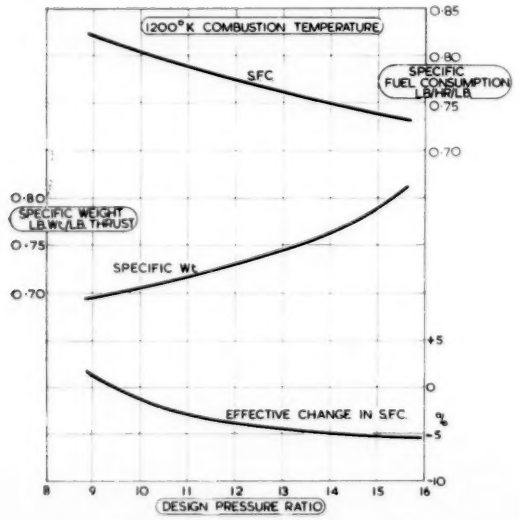

FIGURE 7. Effect of pressure ratio on engine performance at a Mach number of 0·8 at 36,000 ft.

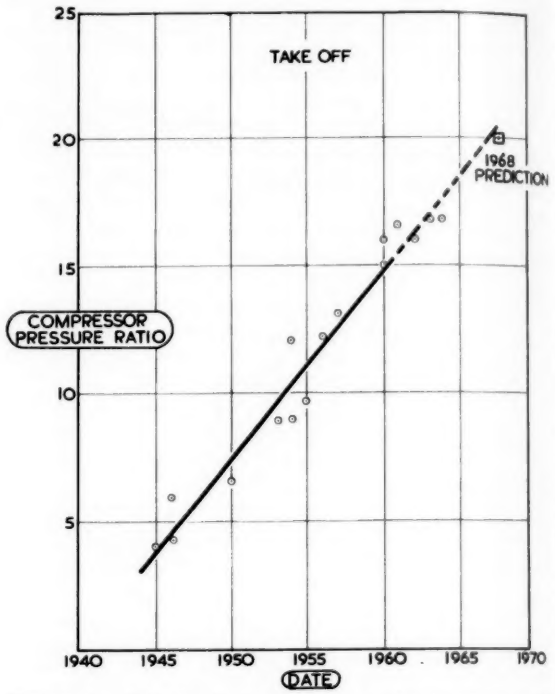

FIGURE 6. Increase in gas turbine engine pressure ratio turbo-jets.

importance of fuel consumption and engine weight for a given aircraft duty is fairly well defined, and this leads to the effective change in specific fuel consumption shown on the graph. It may be seen that apparently little improvement is to be obtained by increasing compression ratio much above current values.

The optimum value of pressure ratio is, however, very dependent on the value of combustion temperature being used. If this increases at anything like current rate of development it will mean that it is more worth while to exploit increased pressure ratios. It appears to me, in fact, that pressure ratio is likely to be restricted more by technical feasibility rather than by necessity. In the predictions that will be made in this paper I have adopted a common time of about seven years; in this period I believe a pressure ratio of 20 could be achieved without any basic modification to the two-shaft configuration of current engines.

2.3 COMBUSTION TEMPERATURE

Combustion temperatures employed on engines tend to separate into groups depending on whether blade cooling is used or not, but Fig. 8 shows that temperatures are rising continuously and with the spur towards supersonic aircraft this progress should continue. Fig. 9 shows the gain in aircraft operating economics that would result from increases in combustion temperature at various by-pass ratios. It will be seen that whereas for a straight jet engine, combustion temperature has little effect on economics but increases the take-off noise level, at higher by-pass ratios a very worthwhile improvement occurs. If by-pass ratio is increased at the same time, the

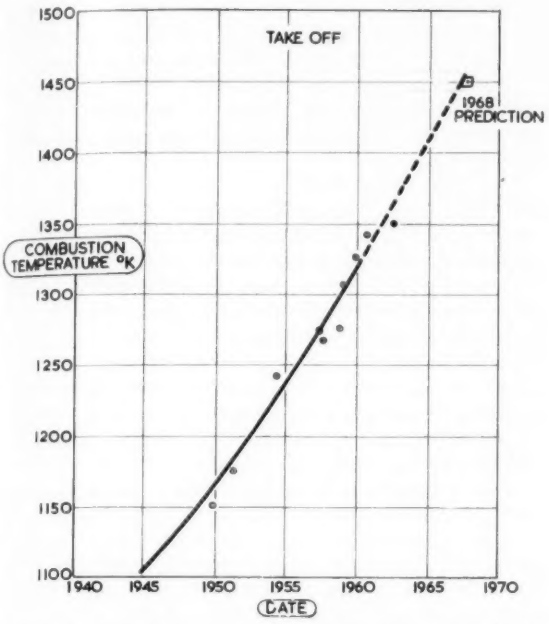

FIGURE 8. Increase in combustion temperature for turbo-jet engine.

level of noise can be maintained constant while keeping at the most favourable economic point.

Again, for the purposes of prediction it is considered that in seven years a cruising temperature of about 1,350°K could be achieved, but clearly, coupling it with possible increases in pressure ratio already described, will make the cooling problem more difficult. The take-off combustion temperature equivalent would be about 1,450°K. The reasons for assuming that high temperature alloy development will make such advances possible are discussed in more detail in the section on Supersonic Aircraft.

2.4 COMPONENT PERFORMANCE

In my opinion it would not be wise to count on much improvement in component efficiency in the period considered. Improvements in efficiency are possible but they would seem, on present indications, to be achievable

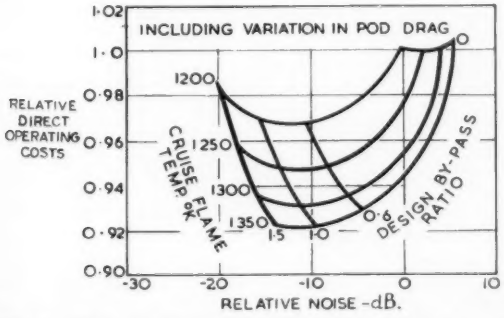

FIGURE 9. Short range transport. Variation of direct operating cost and take-off noise with combustion temperature and by-pass ratio.

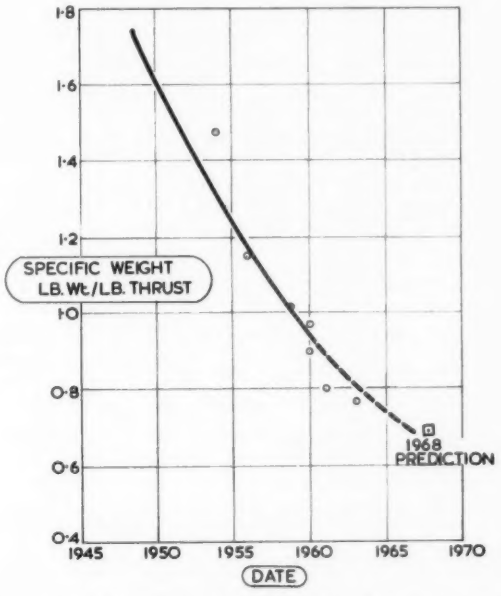

FIGURE 10. Change in specific weight of turbo-jet engine 550 m.p.h. 36,000 ft.

only at some cost in increased weight, bulk and frontal area. Only the component developments to keep pace with the increases in pressure ratio and combustion temperature are therefore relied upon in this lecture.

2.5 WEIGHT

Inevitably increased pressure ratio, and to a more limited extent increased combustion temperature, will tend to increase engine weight, although the latter will certainly tend towards reduced specific weight which is its main justification. Fig. 10 shows the gradual improvement in specific weight. Further improvements will arise from design improvements, the more extended use of titanium, although the latter is usually reflected in increased cost, and possibly from the introduction of plastic components in the cooler portion of the compressor casings and blading. I believe it should be possible by these means to keep the weight of the increased pressure ratio engine down to current values, the increase in combustion temperature then operating as a direct reduction in engine specific weight.

2.6 PROGRESS IN THE FUTURE

Figures 6, 8 and 10 have shown how the pressure ratio, combustion temperature and engine specific weight have improved with the years and have indicated possible development for the future. Fig. 11 shows the way engine specific fuel consumption has also improved, a representative flight consumption being used, as the only one with much significance. Fig. 12 shows a photograph of the RB.141 engine which is representative of a modern design of by-pass engine, having a take-off thrust of 15,400 lb. The RB.163, which is in most respects a scale-down of this engine and is already under development, will power the de Havilland 121 aircraft.

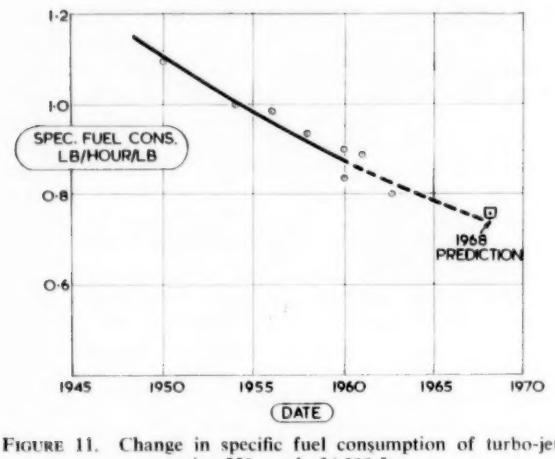

FIGURE 11. Change in specific fuel consumption of turbo-jet engine 550 m.p.h. 36,000 ft.

From what has been said before, it should be possible by, say, 1967 or so to contemplate for an engine in the 10,000–20,000 lb. thrust size, a pressure ratio of about 20 and a temperature of about 100°C above that of current engines. Such an engine would give about 18 per cent more take-off thrust than a current engine for the same air flow, and would thus be this much lighter for a given thrust. It would also have about 23 per cent more cruising thrust, but the specific fuel consumption would be about 3½ per cent greater. As engine specific weight would be about one-quarter of the importance of fuel consumption, it is doubtful if this would represent a great advance. A more potent objection may be that the engine would be 5 dB noisier.

It would therefore seem more desirable, as may be seen from Fig. 9, to operate at higher by-pass ratios, in fact at constant specific thrust, so that the engine would produce the same thrust per unit air flow and compressor frontal area. Thus the engine noise and pod drag would be exactly as for current engines. The by-pass ratio would be about 1·5–1·6, the specific fuel consumption would be about 4 per cent better, and the specific weight, due to the reduced size of the high pressure components, would be about 10 per cent lighter.

These values are indicated on the appropriate figures for the approximate date. On rough aircraft performance investigations they would appear to indicate something like 6–7 per cent improvement in range compared with a 1960-62 engine.

2.7 INSTALLATION CONSIDERATIONS

I ought not, in discussing trends in aircraft propulsion, to pass over such an important item as thrust reversers. The present period has seen their introduction, and nearly all future projects will make use of engine thrust reversers. They add nothing, of course, to useful propulsion, but a great deal of weight, and the future ought to see some worthwhile reduction in these penalties. I will not take up more space in dealing with these; the development of the current type of reversers has already been adequately described elsewhere.[1]

The present period has also seen an intensive attack on the noise problem. This has resulted in the quite complex types of exhaust nozzle now being used and already described elsewhere[2]; in the development of noise abatement techniques for take-off and a general background appreciation of the various factors involved. All this may be small comfort to those living near a major airport, but the position would have been much worse but for this work. For the next generation of jet aircraft, take-off noise levels will be, in genuine annoyance value terms, substantially below those of the best piston-engined aircraft and some 12 PN dB better than the present long-range jets. Further progress will be limited by the need to reduce other noise sources, the compressor for instance, and may have to take account of the increases in combustion temperature foreshadowed.

The problem of engine noise during landing approach is already tending to assume a greater significance than the take-off noise. At this condition the engine is so throttled that jet noise is negligible, but the aircraft is much closer to the ground over the airport community and thus, at least along the direct track of the aircraft, the noise level may be greater. It is in these respects that high

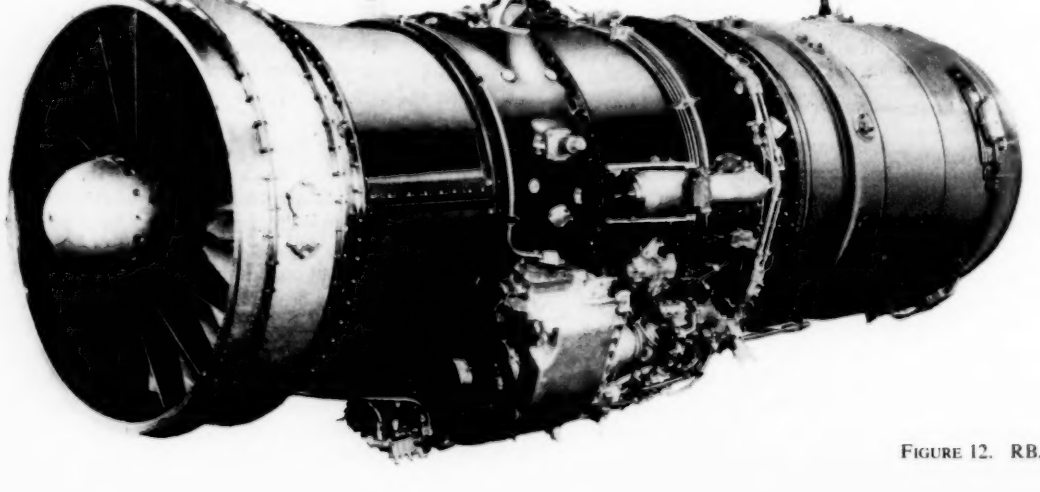

FIGURE 12. RB.141 engine.

by-pass engines tend to show up worst. Already the main factors that govern compressor and turbine noise as distinct from jet noise are appreciated. Methods to obtain a worth while reduction are already known, the problem being mainly one of the economic penalties associated with them as well as the operating restrictions and airworthiness restrictions that might be imposed. Such methods are the use of variable area intakes, which would be closed so as to choke the flow at approach conditions, or variable area devices within the engine. The possibilities of aerodynamic design to produce engines of low noise output do not appear so promising because noise level appears to vary quite slowly with the main design parameters, whereas some hundred-fold reduction in its intensity is required to produce 20 dB's reduction in noise level.

In the immediate future it is probable that benefits will also be obtained from noise absorption and tuning devices in the engine nacelle; it will be a hard struggle involving small returns from several different methods that will not involve radical changes in operating techniques, or high penalties in weight and cost.

A word should be said about power plant items as distinct from the engine itself. In general the total power plant weight is some 150 per cent of the basic engine, and a good deal of this is rather outside the direct control of the engine designer. If the full returns of engine development are to be obtained there ought to be a similar development in these items, otherwise the percentage is liable to rise markedly.

2.8 SHORT-RANGE JET AIRCRAFT

It is accepted that in the long-range field jet aircraft have already introduced a completely new era in aircraft transport, and this ready acceptance of the attractions of jet travel is rapidly spreading to the medium range. Urgent consideration is already being given to its possibilities over short range routes. In this case the attractions of large reductions in block time are not so apparent, but the other benefits of smoothness, quietness and the accepted reliability of the power plants are genuine attractions. Moreover, even in these fields it is becoming apparent that jet aircraft can be competitive on operating costs, due largely to the low power plant weight.

In this field low engine cost is of paramount importance. In the long-range application the demand for minimum fuel consumption has led to the development of ever more efficient engines, but inevitably engines of greater complexity and therefore of higher cost. In the application to short-range aircraft, fuel consumption is not of such relatively great importance, a low power plant weight and first cost being in some respects more attractive features. This field, therefore, represents a nice exercise in the design of simpler engines, of higher fuel consumption, but of reduced weight and particularly, cost. Pressure ratios will probably be restricted, combustion temperatures may have to be limited such that blade cooling is not required, and engine designs arranged so that critical and expensive materials are not required. Such steps will lead to cheap first cost aircraft and they will be competitive on operating costs at the short ranges at which they are designed to operate, but flexibility will be lost in that at longer ranges, or where aircraft are required to carry out successive short hops without refuelling, operating costs will tend to rise due to the higher fuel consumption. This field is of great interest but is very much in the earlier stages of investigation at the moment.

3. PROPELLER-TURBINE AIRCRAFT

Due to the tremendous impact of jet travel the future of turboprop aircraft remains somewhat in doubt. This, to many, seems surprising after the great success of the Viscount which is carrying a substantial portion of the free world's air traffic. Nevertheless, the fact remains that second generation aircraft of this type have been difficult to sell in sufficient numbers.

The arguments previously put forward for jet travel may be considered as all very well in themselves and especially attractive to "expense account" passengers, but it may be argued that for a very large number of potential passengers who would have to pay their own fares, aircraft travel is already so much faster than other methods, that the main concern is with much reduced fares. In this field it has been widely stated, the turboprop air liner offers the best hopes of really low fares. It is not proposed to argue this further here; clearly, however, to allow this type to show its full capabilities, engine performance should be offered at the same level as for jet aircraft.

It is undeniable that turboprops have not developed at the same rate as pure jet engines. The reasons for this are not far to seek. First, they have not been required to anything like the same extent for military purposes, and secondly, they are intrinsically more complex, requiring the addition of reduction gears, and airscrews

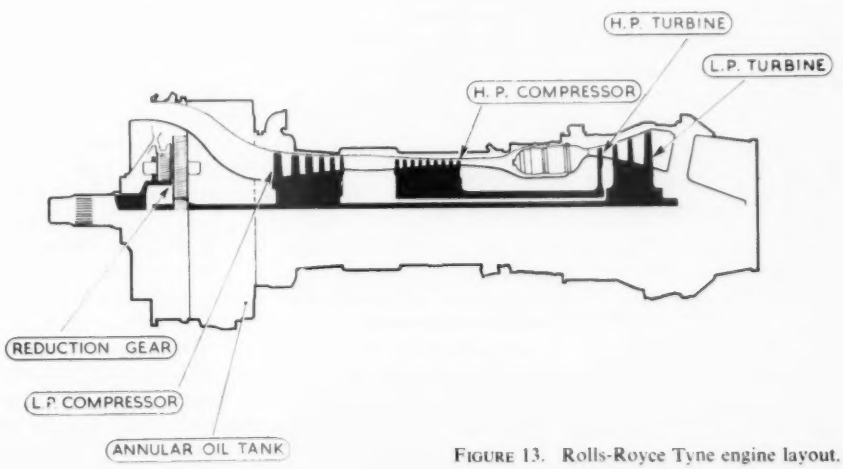

FIGURE 13. Rolls-Royce Tyne engine layout.

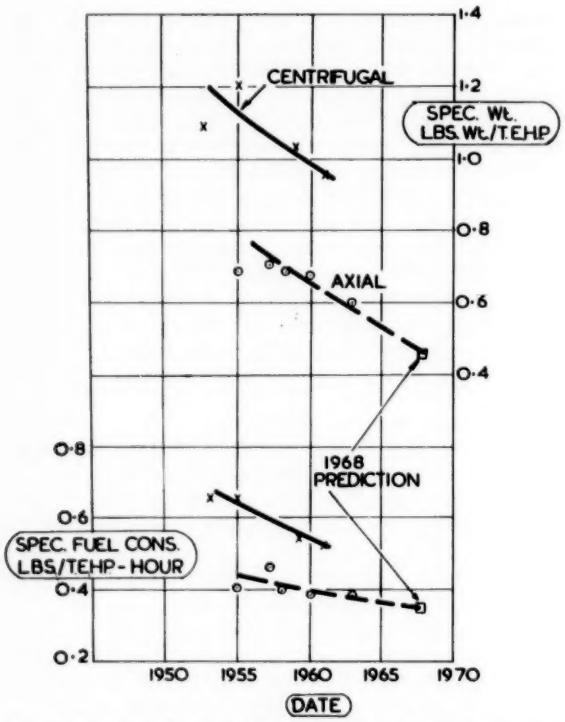

FIGURE 14. Propeller-turbine change of specific fuel consumption and specific weight 300 knots-25,000 ft.

with their control mechanisms as well as extra turbine stages to produce the shaft power. An additional important point is that the purely turbine portion of the engine is not by any means the whole of the engine, and development of this to the same degree as the jet engine still leaves the bulk of the reduction gear and the airscrew unchanged, so that the advantages from such developments are less marked. Fig. 13 showing the Tyne engine, which is the most modern turboprop engine available, illustrates this point. In fact it is the airscrew spinner size that dictates the size of the gear casing, not the gearing itself.

As opposed to the numbers of advanced jet engines in the world, this is the only really advanced turboprop engine available. It is of similar technical standard to the Conway engine, having a similar overall pressure ratio.

Figure 14 shows the progress of propeller turbines over the years to this position as regards specific fuel consumption and specific weight. The gradual improvement of the centrifugal types which have given such "yeoman" service is exceeded by the more modern axial types.

Improvements in performance will come about through the raising of combustion temperature and pressure ratio and from improvements in design and weight. It will be instructive to consider these possibilities. Fig. 15 shows the progress of combustion temperature and pressure ratio through the years which has led to the improvements shown in the previous Fig. 14. The question is naturally, will it be desirable to increase these in the future?

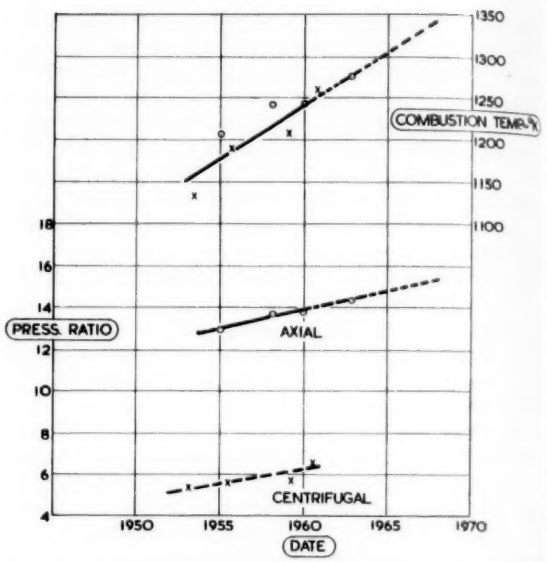

FIGURE 15. Propeller-turbine change in combustion temperature and pressure ratio take-off.

Considering first combustion temperature, the turboprop engine benefits in both specific weight and specific fuel consumption, because it yields directly an increase in power and also improves the cycle efficiency without the corresponding disadvantage as on a jet engine, of spoiling propulsive efficiency. Fig. 16 shows the reduction in these quantities as the temperature is raised. Again, the relation between specific fuel consumption and engine weight improvement is known approximately and the lower curves show the overall improvement. There is not the slightest doubt, therefore, that turboprops will gain from the highest combustion temperatures that can be employed. Provided that engines are allowed to grow in power, that is, we are not faced with designing smaller and smaller engines, there is no reason why this engine type should not employ similar combustion temperatures to those already specified for jet engines, that is, a cruising temperature of 1,350°K towards the end of the next decade. This alone, compared with current values, will give a 7 per cent improvement in aircraft range.

Consideration of pressure ratio (Fig. 17) on performance indicates that even at current cruising combustion temperatures the pressure ratio should be in the region of 16 or above. At higher temperatures even higher pressures are desirable and here again technical feasibility will be the main restriction. It would be wise to assume that the turboprop can benefit from the same technical developments as jet engines and I have assumed that a compression ratio of 20 will apply to an engine of approximately 1967 date.

The question of weight is a more difficult one. Obviously the engine can benefit from the same advances in materials and design as jet engines. In addition, there is a further development that is possible in that such engines have much smaller inlet air flows to their compressors than have been developed for jet engines.

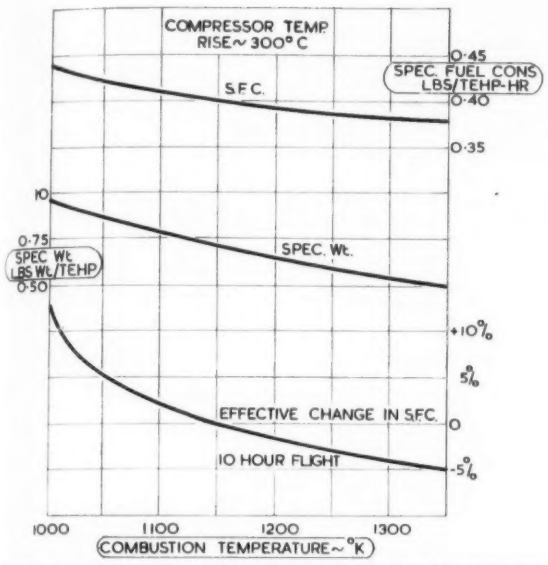

FIGURE 16. Propeller-turbine effect of combustion temperature on power plant performance 300 knots-25,000 ft.

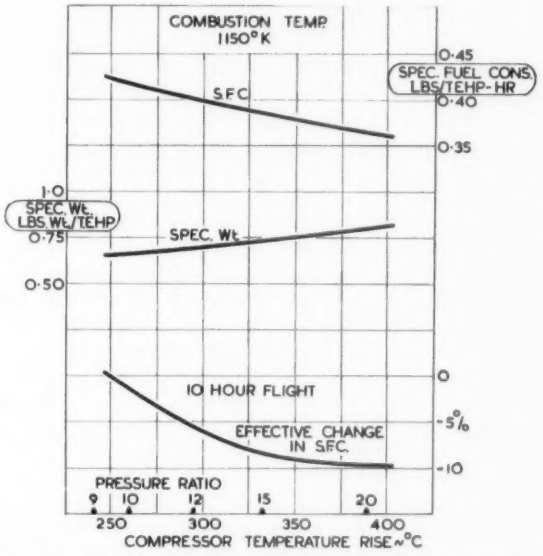

FIGURE 17. Propeller-turbine effect of pressure ratio on power plant performance 300 knots-25,000 ft.

Thus the air flow into the compressor may readily be increased by addition of stages to the front of the compressor. If such compressors were used an appreciable further saving in weight could be obtained, but at the expense of a proportionately smaller compressor lying behind the reduction gear, and also a somewhat higher reduction gear ratio.

The reduction gear remains a problem of its own and it might be presumed that little reward from development could be expected. Perhaps there is a ray of hope in the Novikov gearing system. But obviously as the power output of a given size of engine is increased, the airscrew size also will increase. This means yet a bigger spinner and higher reduction gear ratios.

For all these reasons, therefore, I think it probable that engines to such high pressure ratios as I have indicated could be developed with some reduction in engine weight for a given air flow capacity. The increase in combustion temperature would thus give a greatly reduced specific weight. Such an engine of roughly the same dimensions as the present Tyne would then give an increase in power of about 16 per cent coupled with a reduction in specific fuel consumption of 8 per cent for a given air flow. The air flow could be increased by about 20 per cent, yielding a power increase of 39 per cent. Making allowance for the increased weight of the reduction gear would yield a net gain in specific weight of 20 per cent. These possible gains in performance are shown on the appropriate figures referred to previously. Such an engine of approximately Tyne size would have a take-off power of about 8,000 s.h.p. and would require a propeller diameter of nearly 20 ft., and the weight might be double that of the existing engine. This would mean that the overall specific weight of engine plus propeller would remain about the same.

The performance of such an engine is rather dependent on its being of "large" power. Scaling of the engine down to present or lower powers, *i.e.* 4,000 h.p. or below, would lead to small blade sizes, particularly in the high pressure end of the compressor and also in the high pressure turbine. Consideration of maximum blade chords, particularly when blade cooling is used for the turbine, would probably mean rather excessive weights for these parts, so that engine specific weight would be increased to some extent.

3. The Supersonic Transport Aircraft

The Royal Aeronautical Society have already, organised a symposium on this subject,[5] and more was said at that than I can speak about in the short space of time tonight. It would be inappropriate to avoid mention of this subject in such a paper, however, and I propose to attempt a short summary of the expected trends in engine development to cater for this aircraft.

Supersonic flight presents the turbojet engine in its most favourable light, because at, for instance, a Mach number of 2·0, the pressure ratio in the engine intake is already about seven, so that the engine works at a high pressure ratio; and due to the high forward speed the propulsion efficiency is high. Thus the engine overall efficiency is of the order of 35 per cent at this Mach number, which compares quite nicely with the best Power Station practice. Unfortunately, we have grown used to stating jet engine performance, as regards fuel consumption, in units that have to be divided by the aircraft speed to have any significance as regards efficiency. Thus, although at high Mach numbers the specific fuel consumption (lb./lb./hr.) is some 60–70 per cent higher than engines at subsonic speeds, when divided by aircraft speed the figures show at least a 50 per cent advantage. I notice, by the way, that the aircraft people have tended to write the aircraft speed with lift-drag ratio into a so-called "aerodynamic" efficiency, but in my view this is misleading.

The second point about supersonic flight is that as the lift-drag ratio of the aircraft is low, about half that of subsonic jets, the amount of engine thrust that has to be installed is high. Fortunately, engine thrust rises somewhat at these high speeds, due to the ram pressure built up in the intake, but unless high combustion temperatures are used, the weight and size of required engines becomes prohibitive. Thus the success of a supersonic transport aircraft turns to a large extent on the ability to run engines at high combustion temperature.

Thirdly, the power plant will grow in importance relative to the engine. Due to the fact that the pressure rise in the intake is greater than that of the engine, this will become an extremely important component and of similar bulk to that of the engine, requiring a control system of its own. Again, due to the high pressures developed in the jet pipe, efficient supersonic expansion of the jet gases is necessary, and thus a somewhat complex and variable nozzle is required. The engine itself does not require to be of very high pressure ratio, since that in the intake is already high. In fact, apart from high combustion temperature, the engine itself becomes much simpler than current types.

Nobody has yet assessed the correct flight plan for such aircraft. Due to the intensity of noise from "Supersonic Bangs," the height at which transition to supersonic flight takes place is debatable at the present time. If this becomes very high, then a large thrust must be installed, and this will probably call for some degree of reheat in the engine.

At the same time the engine noise at take-off and landing has to be kept to no more than present jet aircraft.

I would like to deal briefly with some of the foregoing points. First, as regards combustion temperature, it would appear that values as great as 100–200°C higher than current value will be necessary to meet the propulsion requirements, that is, cruising temperatures of about 1,350°K will be necessary. Analysis of the operating temperature and compressor delivery temperature shows that both will be somewhat similar to existing engines at take-off. We are thus faced with the task of operating continuously at current take-off conditions.

Blade Cooling development is continuing and improvements in cooling have been obtained on actual engine type blades. However, cooling temperatures are high and a substantial amount of the increased operating temperature must come from improved turbine blade materials. To meet the requirements a material about 100°C better than current material, at the same conditions of stress and life, must be forthcoming. That this appears possible is shown by Fig. 18 which illustrates the development over the years.

This section is written largely on the assumption that the cruising Mach number will be about 2·0–2·2. Figures as high as 3·0 have been discussed; if these were decided on, the influence on engine design would be more profound. At the lower speeds, engine temperatures as regards compressor materials and bearing temperatures are not such as to make them vastly different from current high pressure ratio engines.

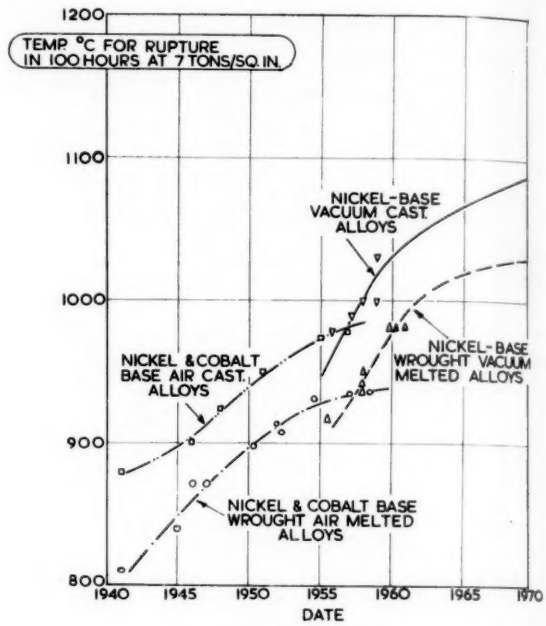

FIGURE 18. Turbine blade operating temperatures.

To meet the efficiency requirement of the air intake, and to match it to the engine so that large "spillage" drag does not occur, an intake of variable centre wedge type is required, and this also has to be provided with spillage vents. Control of the centre wedge angle and this spillage has to be exercised as a function of the aircraft forward speed and engine speed. The control system requirements are shown in Fig. 19; it is clear that such a power plant system will need a great deal of development. The air intake itself will probably feed two or more engines side by side; it will therefore be "two-dimensional," but the requirements of providing for engine failure introduce important qualifications.

I believe the design of the rear end of the engines, *i.e.* the propulsion nozzle, represents the least well understood problem in the engine. The pressure ratio of the expanding gases in the jet pipe is such that a convergent-divergent nozzle is required. Unfortunately, at take-off and subsonic flight, the pressure ratio is quite low. If a convergent-divergent nozzle were used the losses in the latter condition would be large and also, instability of flow would result, with the result of large fluctuating forces applied sideways on the nozzle. Thus a variable nozzle of some type must be used. However, at low supersonic speeds a contracting rear end will involve high base drags which would appear to be of about the same amount as the losses in thrust previously referred to. The possibilities of the ejector nozzle need investigation for this case; but no satisfactory solution would appear to be available yet.

With regard to noise, at take-off although the thrust installed is high, due to the low lift-drag ratio, the height of the aircraft by the time a residential community is reached, is not so high as a similar powered subsonic aircraft. To achieve noise levels that are satisfactory

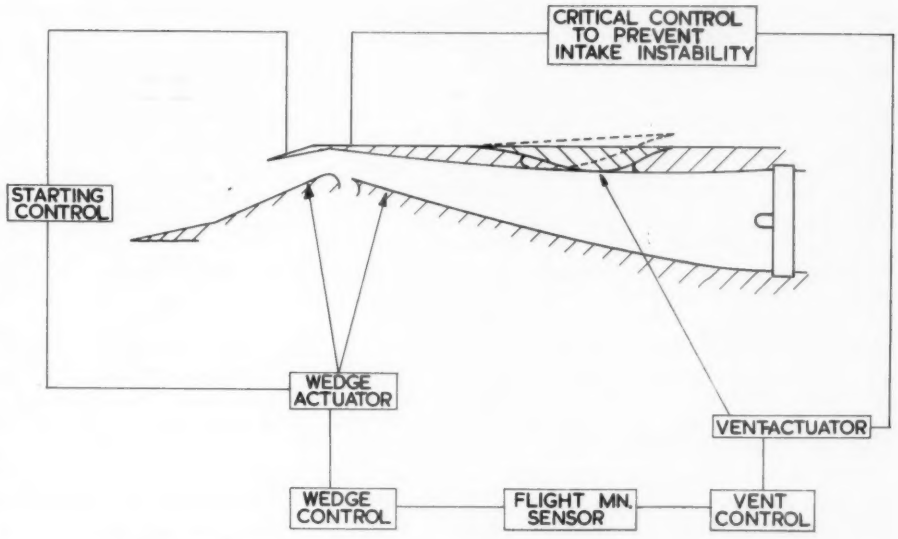

FIGURE 19. Supersonic air-intake control.

will depend on the exact climb technique used; it is not yet clear whether such requirements will dictate the type of engine. The airfield noise itself is fairly certain to present a severe problem. Landing noise will probably present a similar but somewhat worse problem than on current jet aircraft, but as variable air intakes are already required, their use should solve this.

The transition thrust requirement, if large, may have to be met by reheat, as mentioned earlier. An important requirement of such a reheat system is that it must not cause much loss in the cruising and climbing conditions.

Before leaving this interesting design exercise it should be pointed out that the supersonic cruising condition is by no means the only serious requirement of this aircraft. In fact a typical inter-continental aircraft would probably use about one-third of its fuel before actually reaching cruising altitude, so the importance of an engine which also has good subsonic performance will be appreciated.

4. V.T.O.L. and S.T.O.L. Aircraft

V.T.O.L. type aircraft have now been studied for some time and the general conclusion seems to be that except perhaps for some military types, it is farther away than had been hoped. Fortunately, this lecture is concerned with the propulsion of aircraft and therefore will not concern itself directly with "lifting" power plants—they have been, in any case, dealt with elsewhere[3]—except in regard to the type of propulsion power plants.

V.T.O.L. has been investigated for both transport type aircraft and also for military interceptors and strike aircraft. The solutions have been many, tilting wings, deflected slipstreams, separate lift engines and fans and deflected jets.

For tilting wings and deflected jets the type of power plant is generally the turboprop so that the engine type is not markedly different from that already discussed. The difference lies in the amount of power that has to be installed and the complication of shaft drives, and so on. In the normal cruising condition, therefore, the engines either have to be throttled back or some engines shut down. The same holds true of the deflected jet engine. Only the separate jet solution allows propulsion power plants to be chosen solely to power the aircraft in the most efficient manner, but in this case the added weight and bulk of the lifting engine becomes an additional penalty. Such engines have been developed to an extent where this system promises to reduce the penalties to a possible acceptable order. However, the requirements of low noise and in some cases longer periods of purely vertical flight, cause doubts on their feasibility.

It seems to me that for transport aircraft no completely acceptable solution has yet emerged from these studies and perhaps this is because design has rather tended to be in the direction of adapting various lifting systems into generally conventional aircraft designs. If low noise level is to be attained, low jet velocity is mandatory and it may be that more success will be achieved by designing the aircraft round a propulsion and lifting duct system. In any case the solutions proposed are so varied and the eventual solution so difficult to foresee that it seems difficult to predict what the trend of propulsion power plants will be in this field.

For the purely military aircraft, interceptor or strike aircraft, where V.T.O.L. may be required as an operational advantage or necessity, certain trends can be indicated. First, for the high performance interceptor, the thrust requirements will probably be such that the propulsion power plants are capable of lifting the aircraft off vertically. In this case the engines may be designed for the high speed requirement, and V.T.O.L. may be obtained either by rotating the power plants (in external pods) into the vertical position, or by deflecting the jets downwards.

For strike aircraft, where a high Mach number performance is not required, two competing solutions are offered. In the first a combined by-pass type power plant is used to give a high thrust and the whole of the thrust is deflected at take-off, this being represented by the Bristol Siddeley BS.53 engine in the Hawker P.1127. The advantage of this solution is that only one power plant is used, the disadvantage that in the subsonic cruising condition, because the installed thrust is so large, the engine is heavily throttled back and the consumption is impaired. The engine tends to have a large cross section which spoils any supersonic prospects,

although if reheat were added, no doubt there would be plenty of thrust. Safety in the event of engine failure is a doubtful quantity.

The alternative solution is to provide the lift from several special lightweight lift engines and to power the aircraft with a separate propulsion engine which is correctly chosen for optimum propulsion performance. The latter may have a deflected jet for take-off if desired. The advantage of this solution is that optimum propulsion efficiency can be retained and safety in the event of engine failure ensured. Obviously the disadvantage lies in the provision of several lifting engines. The Short SC.1 is an experimental aircraft to investigate some of the problems of this solution. Obviously the fact that there are two such competing systems means that these advantages and disadvantages are assessed differently at the moment. The next four years should obviously see important development in this field.

S.T.O.L. aircraft I tend to regard as being like V.T.O.L., "only less so." By this is meant that where extra lift is obtained by the direct action of the engine thrust it only means that less thrust in the downward direction is used. However, there remains an important class of solutions which aims at increasing the wing lift by "super circulation," blown flaps and the "jet flap."

The whole of this field needs, and has received, a separate lecture. From the propulsion engine viewpoint, however, it is clear that these proposals point to engines providing substantial quantities of rather "cold" air to the wings and flaps, *i.e.* to another class of by-pass engines. Even in this case, however, the possible solutions are so many, and some of the disadvantages so obvious, that it is extremely difficult to attempt to detect any "trend" in the development of possible power plants.

Summarising, it appears that apart from the military strike fighter and interceptor, the possible designs are so varied, the problems so manifold but the rewards so great, that successful applications should come but must be some way away. Nevertheless, the field is a challenging one and one in which a solution will eventually be found.

4.1 HELICOPTER POWER PLANTS

Due to limitations of space and time I have not attempted to deal with this most important class of machine. My omission in this case should rather be put down to lack of capability than to desirability.

5. Military Aircraft

For obvious reasons it is desirable to keep this section as general as possible. For bombers, transports and long-range reconnaissance machines it is clear that the general situation as regards propulsion is not different in kind than that for civil transport machines, and this applies whether the machines are sub- or supersonic. The V.T.O.L. and S.T.O.L. type of interceptor or strike aircraft has already been mentioned in the previous section. There remains the important case of supersonic performance of aircraft that for reasons of manoeuvrability, patrol, etc. have to have essentially subsonic performance, but supersonic capability. For such aircraft very high propulsion thrust from low engine size and weight is the main requirement.

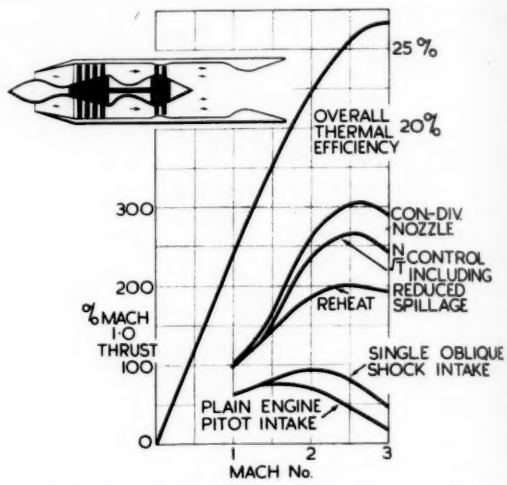

FIGURE 20. Potential thrust of developed jet engine.

Figure 20 shows the potential thrust with increasing forward speed of the straight jet engine. The important gains to be obtained from reheat, speeding up the engine at high forward speeds (N/T control so-called) and from convergent-divergent nozzles is apparent, so that at Mach 3·0 there is three times the thrust available as at Mach 1·0. In this graph the engine is chosen in pressure ratio, and so on to suit the Mach number required; obviously this entails limitations on its subsonic performance. Where the latter is of most importance, there is a tendency to employ efficient by-pass engines, which by afterburning can give a large thrust boost for supersonic performance. However, for this latter condition alone they are not as suitable, on account of weight and bulk, as the simple jet engine.

For our purposes here the question to be asked is where does the ramjet, or even rocket engine, fit in? Ignoring take-off conditions, this is obviously not until some high Mach number is required, say well beyond 2·5. Oddly enough, however, this figure has been retreating as long as the author can remember. Initially it was between 1·5 and 2·0, then when it was shown that the jet engine could perform well at these speeds, the

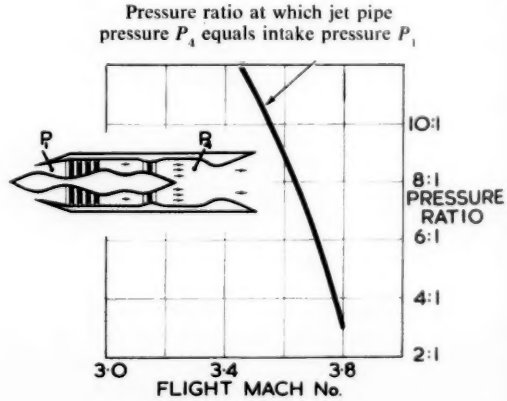

FIGURE 21.

figure retreated to 2·5, then back to 3·0 where it has a tendency to be at the present time.

Figure 21 is instructive for this purpose, and shows the flight Mach number at which the jet pipe pressure falls to that of the intake pressure. Obviously under these conditions, again neglecting any boost considerations, a ramjet would perform equally well, and when weight is taken into consideration, the limit might be expected to be at somewhat lower Mach numbers than in this diagram. The specific fuel consumption of the ramjet engine, at similar specific thrusts, begins to increase substantially below these speeds however.

When weight is taken into consideration a somewhat complex picture develops in that the required altitude of flight becomes a most important criterion. Summarising, however, it would seem that for reasonable supersonic endurances, say thirty minutes to one hour, and making allowance for boosting, the jet engine is superior up to an altitude of some 60,000 ft. and to a Mach number of 3·0. As height increases the advantage tends to pass to the ramjet. Eventually, with very high speeds and altitudes, a rocket power plant is best.

It seems to me that to design a high altitude aircraft of a Mach number substantially higher than 3·0 will become a possibility and that a ramjet power plant will be required. For take-off and lower flight speeds a turbojet will be required and probably the most suitable system will be the ducted jet engine (Fig. 22). It is interesting to see that this system has already been explored at lower Mach numbers by the French, and the Society was privileged to hear a paper read by General Daum on the "Griffon" in March 1959[4].

It will be seen therefore that military aircraft have some way to go before the possibilities of the jet engine are exhausted. In the near future it will be safe to predict that light weight low or medium pressure jet engines with high boost reheat will be developed for supersonic interceptors. Also it is to be expected that "militarised" versions of civil by-pass engines will be used in aircraft of the "strike" type, possibly fitted with reheat systems to give supersonic capability. The possibility of a ducted jet engine is entirely dependent on the estimated "need" for a really high Mach number interceptor.

6. Conclusion

I am aware of the unevenness of this presentation in the trend of propulsion power plants. Generally speaking I have tried to deal more at length with those sections where the requirements and limitations are more precise and the trend more discernible, and less with those where doubts and difficulties seem to be alone observable. To deal with these at greater length would only have lengthened the paper and complicated the discussion without making any trend more apparent.

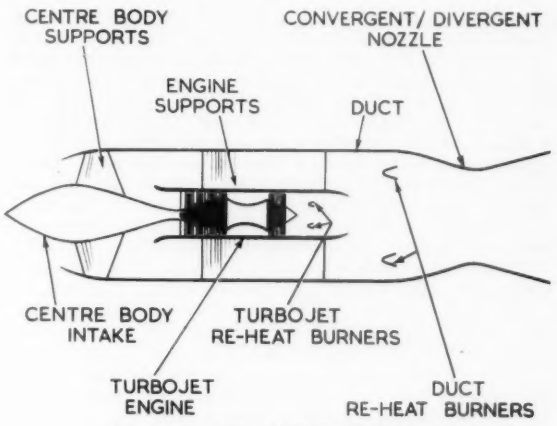

FIGURE 22. Ducted jet engine (Leduc).

I am indebted to Messrs. Rolls-Royce Ltd. for permission to give and publish this lecture, and to my colleagues with whom work and discussion has led to the views expressed here. Naturally, however, the responsibility for the views expressed here is my own, although I believe and hope that many will be common property. In particular I would desire that the responsibility for my views on possible performance of engines in the future should be restricted to myself.

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DISCUSSION

The Chairman : Earlier in the evening he had described Mr. Pearson's lecture (which he had been privileged to read) as promising to be informative, entertaining, and perhaps somewhat disputatious. There would be no doubt now of the first two adjectives; whether or not the lecture was disputatious would be proved by the discussion.

Handel Davies (Deputy Director (Air), R.A.E., *Fellow*): He found this lecture most instructive and enjoyable, and even those who were not very familiar with engine development had been able to gain a great deal of knowledge from it. He would like to expand a little on what Mr. Pearson had said, stating a few of the implications of changes in specific fuel consumption, engine costs and other engine parameters, on the overall characteristics of aircraft. Taking the two main cases which Mr. Pearson took in the lecture, subsonic and supersonic aircraft, if one made a 10 per cent change in first cost of the engine, one found that the change in direct operating costs was only about 2 per cent, whereas a change of 10 per cent in specific fuel consumption was 8 per cent for the subsonic case and 20 per cent for the supersonic aircraft. Thus one could afford to let the first cost go up quite a large amount provided one got an appreciable gain in specific fuel con-

sumption. A 10 per cent change in engine specific weight meant a 3 per cent change in operating costs for subsonic, and 6 per cent for supersonic aircraft. Another significant example, he thought, concerned maintenance costs or overhaul time; a 10 per cent improvement in that, which was not a very ambitious aim, could mean 3 per cent improvement in direct operating costs for subsonic and 4½ per cent for supersonic aircraft. All this merely supported some of the things Mr. Pearson had said. He thought the outstanding figure was the tremendous importance for supersonic transport of keeping specific fuel consumption low, even at the expense of considerable increase in fuel cost.

There were two points of detail in the lecture on which he would be grateful for some clarification. The first concerned Fig. 2. Elementary considerations from first principles would suggest that the specific weight should be very roughly a linear function of the by-pass ratio. Could the lecturer say what were the practical considerations which caused the specific weight to increase so much more rapidly with by-pass ratio? The other point concerned Fig. 5, from which it seemed to him that it could be deduced that the *total* noise continued to decrease up to much larger by-pass ratios than the optimum suggested by the lecturer.

On the general question of noise, he would like to utter a faint note of warning regarding the assumptions which were currently being made on climb techniques immediately after take-off. There was a tendency to assume that with supersonic transports larger angles of climb would be used than with the present jets in order to relieve the noise problem. Angles of climb of over 10° had been mentioned. It must be remembered that with a wing incidence of perhaps 13° and a large apparent attitude associated with acceleration, the passengers would get an impression of an attitude approaching 30°. This mundane point should not be accepted too complacently, and it had a bearing on such questions as optimum by-pass ratios.

Mr. Pearson: He did not know why, as an airframe man, Mr. Davies did not also put down the effect of a 10 per cent change in lift/drag ratio for it would be found that the aircraft was pretty sensitive to this. In some respects also the allocation of the descriptions super and subsonic to these aircraft was really somewhat unfair, because largely what really mattered as to the effect of these variables was that the percentage of load being carried was very small in the supersonic case. If a subsonic aircraft operating at such a low load percentage were considered, the effect of the variations in parameters would be equally significant. The unfortunate fact was that the type of supersonic aircraft Mr. Davies was thinking of was carrying a small load in proportion to its all-up weight. This seemed to be the present technical case when one considered the design of such an aircraft for London to New York for instance.

With regard to the point about Fig. 5 and the total noise, Mr. Davies would remember that one could not add decibels together by simple addition and deduce that the total noise continued to decrease up to much larger by-pass ratios than the point at which the two noises were the same. Remembering that decibels were in fact a logarithmic scale, then where any one noise was several decibels lower than another, then in general one could disregard completely the lower. On the assumption that the noises could be added together logarithmically one in fact found that the noise level was very flat between by-pass ratios of 0·8 and 1·5, and therefore there was really no point in raising the by-pass ratios to the high values from the point of view of silencing.

With regard to the angle of climb being used in studies of the take-off technique for supersonic transport, he agreed with Mr. Davies, but the whole question of take-off technique was in a great state of flux, and he thought it was probable that the eventual solution would be at much lower angles of climb, such that the passengers would not be incommoded. All this was a matter for the aircraft designer rather than the engine manufacturer, but it all had a combined effect on the noise that the engines in a supersonic transport would make on take-off.

Returning now to the comments on Fig. 2, the detailed reasons why the specific weight increased non-linearly with by-pass ratio he thought could be expressed in the following way: starting with a plain jet engine and increasing the size of the low pressure compressor and turbine to drive it added a certain weight, but at the same time the greater mass flow of air also increased the thrust. As the air flow was further increased the weight increased directly proportional to the increase in air flow, but the thrust increase did not do so particularly when one was considering the conditions at the altitude cruise conditions. Thus the specific weight tended to stay almost constant for small increments in by-pass ratio but increased faster at the higher by-pass ratios. The curve he had shown was, in fact, drawn through a series of points that they had obtained from a series of design investigations which took into account many conflicting factors and represented their design experience rather than any theoretical prediction.

A. N. Clifton (Assistant Chief Engineer, Vickers-Armstrongs (Aircraft), Ltd., *Fellow*): Bearing in mind that the weight of the engine was, on the modern jet aeroplane, at least equal to or more than half the total weight of the aeroplane, he thought it only fair that aircraft people should try and understand what the engine people were up to and Mr. Pearson had shown that over the years the effectiveness of the engine had certainly been improved.

He had three questions. First, just what did the noise of the compressor vary with? In the past when they had rolled their aeroplanes out to fly for the first time, they had usually found that they weighed more than they intended and sometimes there had been a certain amount of increased weight from the engine side, perhaps in the power plant or the fuel. If they complained to the engine man he pointed out that the power had gone up considerably, and of course, in view of the extra weight of the aeroplane they needed the extra power anyway. Now this was, in a sense, a satisfactory proceeding, but he was under the impression that the way in which the engine power was increased usually made the engine noisier and unfortunately it rather looked at present as though they were designing on a noise limit. Mr. Pearson did show on Fig. 2 that the one hope of reducing noise seemed to lie in increasing the by-pass ratio. Did it follow from this that in the future as they got their weight growth during design they would have to face up to fitting an engine of larger diameter with a larger by-pass ratio than they planned?

The third question related to the problem of the supersonic exhaust nozzle. At present they aimed at constant throat area, and if they had the variable nozzle arranged so that they had a good streamline shape, not causing any base drag, in supersonic conditions, then under subsonic conditions when they adjusted the nozzle to reduce its aperture they got a large base drag something of the order of 10 or 12 per cent of the total drag of the aeroplane. If instead of throttling the engine at low Mach numbers maximum r.p.m. was maintained by increasing nozzle throat area and decreasing turbine entry temperature, the base drag would be considerably less. Was there any possibility of a solution in this direction?

Mr. Pearson: The origin of compressor noise was a complicated subject and there was a risk that any explanations he gave would be a case of the blind leading the blind.

First, in a normal jet engine most of the noise from the compressor emanated from the front through the air intake, presumably because the noise passing out rearwards was damped out after passing through combustion chambers and turbine. Some of the noise from the compressor could be attributed to the pressure distribution round the blades of the compressor. Just as in the case of an aircraft wing there was an associated pressure distribution with a low pressure on the top of the wing and a higher pressure underneath, there was a similar distribution associated with the compressor blade. As the blades were rotating, then to a stationary observer a series of pressure variations would pass the observer and register on the ear as a noise. Normally this pressure distribution would fall off very rapidly with distance from the com-

pressor, but when these pressure variations were fed through a duct, represented by the compressor casing and air intake, a substantial amount of energy was, in fact, transmitted into the open air as sound wave motion, which was radiated more or less uniformly and fell off in intensity as the inverse square of the distance of the observer. Clearly, this type of noise was related in frequency to the number of blades in the compressor and the r.p.m., and what was known as discrete noise, that was, a noise made up largely of one particular frequency, if, for instance, they were considering the first stage of blades alone. Such discrete tones were noticed, but, in fact, the majority of the noise emanating from a compressor consisted of "white" noise, *i.e.* noise having a frequency spread over a very wide range. It was thought that this noise was generated largely by the eddies flowing away from the wakes of blades and it would be expected that the amount of noise would be directly related to the power dissipated in such eddies. It did seem to be true that for any particular compressor the amount of noise was related to the "lost" power, *i.e.* to the Power Input × (1 − efficiency). To be more specific, the "white" noise level of a compressor seemed to vary as the mass flow × temperature rise raised to the 1·6 power.

There were many ways in which engine power could be increased. Putting up the operating temperature was one which would undoubtedly increase the noise level; adding another compressor stage at the front was another well-known method which increased the air flow but would not make the noise level much higher. In general, if they wished to preserve noise levels it would have to be done by increasing the mass flow rather than putting up the temperature, which would increase the jet velocity, because it was the jet velocity which was the largest term in dictating noise levels.

The third question was on supersonic exhaust nozzles. In fact he was considering the question of the engine going at full thrust all the time and the aircraft accelerating through the low supersonic speeds, as for the type of aircraft he was discussing one did not wish to travel at the intermediate supersonic speeds any longer than necessary. The problem could not be so bad as he had envisaged, particularly if the supersonic bang problem dictated reheating in the jet pipe because this itself would dictate an increase in the final nozzle area.

M. J. Brennan (Chief Engineer, Folland Aircraft Ltd., *Fellow*): He was a little surprised to find in this lecture that the engine seemed to be designed around the noise characteristic. From the aircraft point of view noise was a very real thing, but it was in some ways difficult to define quantitatively to the operator. One problem was this: one engineering team might design an aircraft using an engine with a certain noise level, while the competing team might go for an aircraft with an engine of slightly higher noise level. The difference in power output would allow the latter to operate more economically, but the difference of the few decibels involved might be difficult to penalise. Aerodrome runways had presented such a problem in the past. Recently the runway lengths at London Airport were increased, he believed, by 3,000 ft. He believed the result of this had been to change the operating costs between the VC-10 and the Boeing 707. In much the same way an alteration in noise requirements around an aerodrome might change operating costs of different aircraft. Would Mr. Pearson comment on this aspect?

Mr. Pearson: He was sorry that Mr. Brennan was surprised that engines seemed to be designed around noise characteristics, but he felt sure that those critics of the aircraft industry and the airlines who clamoured so much about the problem would welcome the fact that he had spent so much time on it in this lecture.

What Mr. Brennan said was in many respects true; that there were no fundamental limits that the law laid down why such and such a figure of perceived decibels should be made at such and such a distance. It was certainly difficult in the aircraft project brochure stage to assign a merit figure for one aircraft being a few decibels quieter than another. The figure of 112 PN dBs, which he mentioned was the figure laid down at New York International Airport. Its value had some significance; it prevented an operator, using the same type of aircraft and engines as another, from loading his aircraft up and making more noise on take-off because the aircraft was lower as it passed over the built-up areas. They might recollect from Press statements that proceedings were likely to be taken against at least one airline in the U.S.A. for such actions and repeated infringements could even mean that an airline would be forbidden to use an airport. So whether the Aircraft Industry should design for certain noise levels or not, there was no question in his mind that eventually airport authorities would insist on, first, lower noise levels and, secondly, that airlines operated their aircraft so that these levels were never exceeded except under emergency conditions.

Apart from all that, he thought it was correct to take heed of long-suffering humanity distributed around an airport because, in many cases, those people were living there before the airport was built or in any case before the type of aircraft they were considering was thought of.

This was such a well appreciated problem that the airlines themselves were insisting on guaranteed noise levels, so that the engine and aircraft manufacturer had no choice but to attempt to design around the required levels.

Wing-Commander T. R. Cave-Browne-Cave (Engineering Consultant, Southampton University, *Fellow*): Noise abatement was an admirable cause. There were, however, two factors: the magnitude of the sound and also the offensiveness of its character and the circumstances in which it was heard. The offensiveness had by far the greater influence on the distress caused to those who were worried by noise. The magnitude of the sound was easy to measure and was therefore the one at which all the fuss and complaint were aimed.

Mr. Pearson had shown what a great penalty was paid in performance for the last three or four decibels at the top of the permitted maximum. It seemed quite clear that very few people could distinguish between two very loud noises heard at different times if they differed by 3 or 4 dB. They were therefore paying a serious penalty based on magnitude which the sufferer could not even detect.

Offensiveness was a psychological quality influenced by psychological treatment. It was therefore unwise to devote effort to persuading people what a dreadful thing noise was thereby making them more and more conscious and therefore more miserable.

The noise problem, like so many others in engineering, was essentially one in which it was important to determine what really mattered. That was where the work and publications of Dr. Broadbent, Director of the M.R.C. Applied Psychology Research Unit at Cambridge, was so appropriate and valuable. He was shooting at the target which mattered, while enthusiasts and legislators shot at the one which was easy to hit but, for good effect, mattered less.

Mr. Pearson: They were not actually bothered about people being exposed to 85 decibels. The present limits were much higher than that; it was the people nearer the airport who were complaining and being awakened in the night. The present aircraft, Boeing 707, and to a much less extent the Comet, were paying quite large penalties for silencing. For the by-pass engine of unity ratio or even higher, the penalty was not very great, in fact, one of the hopes of the higher by-pass ratio was that it would not need silencing.

Wing Cdr. Cave-Brown-Cave: In the areas where the public were exposed to, say, 110 decibels how many of them fitted double windows?

Mr. Pearson: If he were to rev. up his motor bicycle outside Wing Cdr. Cave-Brown-Cave's house and when he complained, say that he should have fitted double windows, it seemed to him Wing Cdr. Cave-Brown-Cave would have every reason to say "You pay for the double windows and I will fit them." He thought that was what the people living in the neighbourhood of airports would say to the airport authorities. As engine manufacturers, they would

like to avoid the trouble and problems connected with silencing engines, but fortunately this was a democratic world and they had to accept the problem.

A Speaker: He lived five miles from London Airport. If a 707 went over the children would wake, his wife would be roused from sleep. The amount of money people would have to spend on their houses five miles from London Airport would seem quite a burden on them because they could not hope to recover it.

He would like to ask also, was there much noise from combustion?

Mr. Pearson: Before answering the question he thought it would be wise to clarify the different sources of noise and the conditions under which the various noises predominated. First, there was the jet noise, which was noise created by the jet as it emerged from the end of the nozzle. It was a very loud noise associated with a horrible tearing noise that one heard particularly from a military jet aeroplane. It was alleged to be generated by the shearing action between the jet and the surrounding air, and for a particular nozzle the amount of noise varied roughly as a velocity to the 8th or 9th power. Thus this noise was particularly evident at full engine power and diminished as the engine was throttled back. This noise, which was particularly evident on take-off, had been reduced by going to higher by-pass ratios until at by-pass ratios of the order of unity compressor noise became of almost equal significance.

As well as compressor noise there was also noise generated by the turbine for much the same reason as that from the compressor, and this noise emerged out of the end of the jet pipe. It was roughly of the same sort of level as compressor noise. Thus, at take-off in a medium by-pass ratio engine the three noises he had mentioned—jet noise, compressor noise and turbine noise—were of roughly equal significance. At landing, however, where the engine was throttled back to low power, the jet noise made little or no contribution, but the compressor and turbine noise, still of equal significance, were the main sources which could be heard. Thus, to reduce the level of noise at take-off significantly required simultaneous reduction of these three noise sources, because a reduction of any one of the three would only cause minor reduction in overall noise. At landing they had the problem of reducing two noises simultaneously. Therefore the problem of lowering noise level was a complex and probably expensive process.

In addition, the speaker was suggesting that there might be combustion noise as well. Certainly if one listened to a combustion chamber running on its own rig a great deal of noise was heard. This noise was of distributed frequencies and it was hard to say on the record of an engine noise that combustion noise was being picked up. But as one would not expect combustion noise to be completely damped out merely by passing it through a turbine, he would expect some level of combustion noise from the jet pipe.

Dr. D. Cameron (Chief Superintendent, Aeroplane and Armament Experimental Establishment, *Fellow*): He had recently come back to Boscombe Down after a considerable absence and it had been very interesting indeed to hear the progress made in these engines. In 1954 when he was last concerned with aircraft many of the points on these curves were predictions and had since become fact.

Would Mr. Pearson let himself be tempted a little further? Nearly all the predictions were linear ones. Could Mr. Pearson give any indication of the point (and the reason) at which some of these curves might starting turning over?

One other point on behalf of his Establishment. The thing that worried it most at the moment on its engines was not the design performance but the criticality of the adjustments which had to be made to achieve this performance, in the sense of leaving a margin between the operating conditions and any critical conditions, the difficulties of setting and maintaining settings and so forth. Could Mr. Pearson give any idea if the improvements in characteristics which he was forecasting for the future were likely to make this situation either more or less critical?

Mr. Pearson: Although his predictions of combustion temperature and compressor pressure ratio were reasonably linear extrapolations of what had been going on up to the present, in fact his predictions of achieved specific weight and specific fuel consumption were a good deal less optimistic than the linear extrapolations. He had tended to limit his predictions to approximately the year 1968 for the simple reason that it was difficult for anybody to foresee what would happen over a period longer than that. One's first tendency was to say that various limitations were going to prevent further progress and to predict that this would happen. A typical example he could take from aircraft performance would be the fact that in 1935 or so one could predict that high aircraft speeds would be very difficult to achieve and one might have been excused for predicting 500 miles an hour as an absolute limit to a propeller-driven aircraft, but the advent of jet propulsion and swept-back wings removed these hitherto fundamental limitations and a new era of development opened up. Similarly, in the state of the art of jet engines today, the foreseeable development in the future on turbine blade alloys would indicate that the returns for development would fall off rather rapidly. But inevitably something else would turn up to defeat this prediction, such as the successful development of molybdenum, for instance. The short answer was that he refused to be drawn into predicting what was going to happen beyond the point he had.

With regard to the second point that engines were becoming very critical in adjustment, he was very sympathetic with what Dr. Cameron said and knew to what he was referring, but he thought it was largely military aircraft that Dr. Cameron meant. Now, undoubtedly, there were many situations for these aircraft in which the requirements for satisfactory engine performance under very difficult conditions made a severe demand upon the engine. If, for instance, one had to envisage the situation in which the engine was expected to perform perfectly when the aircraft was just reaching the stall, the pilot suddenly accelerated the engine with one hand and fired all the missiles that the aeroplane was carrying with the other, and the engine was not expected even to cough, then certainly some sacrifice in predicted performance undoubtedly had to be made. In such circumstances it was necessary to build in a much greater margin, for instance, between the compressor operating line and the surge lines, such that the performance was inevitably depressed. Sometimes one did wonder how many of these requirements were realistic. He supposed the answer was that until one actually got into combat conditions one never knew, and the natural peace-time policy was to be over-cautious.

L. W. Rosenthal (Isle of Wight Branch, *Associate Fellow*): Perhaps he had been accorded the privilege of proposing the vote of thanks to Mr. Pearson because he came from an overseas branch. He attended the other Main Society Lecture that had been held at this Branch, and felt that this lecture and the attendance had been indeed a very worthy successor. One was fascinated by Mr. Pearson—by the manner in which he took one firmly but gently by the hand, and lead one in such a charming and convincing manner so easily through all the jungle of engine characteristics. He would like to say how refreshing it was to find an engine man talking about cost, almost in a hushed voice; one sometimes got the impression that the term cost in relation to engines was rather a rude word. He was sure Mr. Pearson was making quite a point by suggesting that there would be a lot of better aircraft about if the whole of the design, and not just the engines, had been handed over to the engine companies. However, all of the time they had to have body builders and engine builders, might they have men like Mr. Pearson to come and lecture to them.

Mr. Pearson: He thanked Mr. Rosenthal very much. He did not remember saying anything about handing the whole of the design of the aircraft over to the engine company, but in case the impression was created they certainly did not think they could design better aircraft, in fact they knew little about it. They had had one or two dibs into the business and quickly withdrew. He was sure everyone would agree that they did the best thing.

AIR TRAFFIC CONTROL

An All-Day Discussion on Air Traffic Control was held by the Society on 20th April 1961 in the Lecture Theatre, 4 Hamilton Place, London, W.1. The Chair was taken by Air Vice-Marshal Sir Laurence Sinclair, G.C., K.C.B., C.B.E., D.S.O., R.A.F. (retd.), Controller of Civil Aviation Ground Services, Ministry of Aviation.

Introductory papers were given by Group Captain J. B. Veal, C.B.E., A.F.C., A.F.R.Ae.S., R.A.F. (retd.), Director General of Aviation Navigational Services Group, Ministry of Aviation; Arnold Field, A.R.Ae.S., Master of the Guild of Air Traffic Control Officers; A. E. Slocombe, A.R.Ae.S., Superintendent Air Traffic Services, British European Airways; Air Commodore J. B. Russell, C.B.E., D.S.O., Director of Operations, Maritime Navigation and Air Traffic Control, Air Ministry; E. W. Pike, A.F.R.Ae.S., Manager, Air Traffic Management Division, General Precision Systems Ltd.; J. L. Anast, Director, Bureau of Research and Development, United States Federal Aviation Agency; G. G. Roberts, M.Sc., F.R.Ae.S., Technical Director, Cossor Radar and Electronics Ltd.; Captain V. A. M. Hunt, C.B.E., B.A., F.R.Ae.S., F.I.N., Director, Aviation Control and Navigation Development and Planning, Ministry of Aviation; R. F. Hansford, Display and Data Laboratory, Decca Radar Ltd.; B. N. Tomlinson, Aerodynamics Department, Royal Aircraft Establishment, Farnborough; and J. K. B. Illingworth, Royal Aircraft Establishment, Bedford.

There were discussion periods at the end of the morning session, in the middle of the afternoon and at the end. The discussion was summarised by E. Hanley and H. Keeling of the Ministry of Aviation.

Responsibility of the State for Air Traffic Control

BY

Group Captain J. B. VEAL, C.B.E., A.F.C., A.F.R.Ae.S.

(Director-General of Aviation Navigational Services Group, Ministry of Aviation)

1. Introduction

I shall try to set the Air Traffic Control scene by describing how the responsibilities of States to provide Air Traffic Services are currently exercised in the United Kingdom, and by indicating some of the measures being taken to ensure that these services keep pace with the increasing demands of the air space users. Any opinions I may express are, of course, my own, and do not necessarily reflect the views of the Ministry of Aviation.

2. International Obligations

Under the Chicago Convention, the United Kingdom has undertaken as far as practicable to provide air navigation facilities for international air navigation, and to adopt and put into operation the appropriate standard systems of operational practices and rules which may be established by the International Civil Aviation Organisation (I.C.A.O.) under the Convention. The term Air Traffic Services as used in Annex 11 to the Convention, embraces first the Air Traffic Control Service, whose object is to prevent collisions between aircraft, to prevent collisions between aircraft on the manoeuvring area and obstructions on that area, and to expedite and maintain an orderly flow of traffic; second, the Flight Information Service, the task of which is to provide advice and information useful for the safe and efficient conduct of flights; and, third, the Alerting Service whose objective is to notify appropriate organisations regarding aircraft in need of search and rescue aid, and assist such organisations as required. The needs of each locality are decided by I.C.A.O. Regional Air Navigation meetings, a Regional Plan being produced covering Air Traffic Control Procedures, and navigational, communications, meteorological and Search and Rescue Services. Member States implement as far as possible those parts of the Regional Plan which affect the air space for which they are responsible.

3. U.K. A.T.C. Organisation

The Air Traffic Services provided in this country are too well known to require detailed description. Briefly, they are based in the main on the controlled air space system, comprising airways, along busy routes; terminal control areas, where a series of busy routes converge on major traffic terminals; and control zones to serve the approach and departure paths of traffic at major civil aerodromes. Within these air spaces, and at State-operated civil aerodromes, and certain other aerodromes which have been returned to municipal ownership, Air Traffic Control is exercised by Ministry of Aviation controllers. The major centres of control are the Southern, Northern and Scottish Air Traffic Control Centres, which provide A.T.C. in the controlled air spaces within their respective Flight Information Regions, and Flight Information and Alerting Services for all traffic both inside and outside controlled air space. Much of the controlled air space system extends to a height of 25,000 ft. Above this, to cater for the increasing numbers of civil jet aircraft, a network of upper air routes has been introduced. On these, normal procedural control

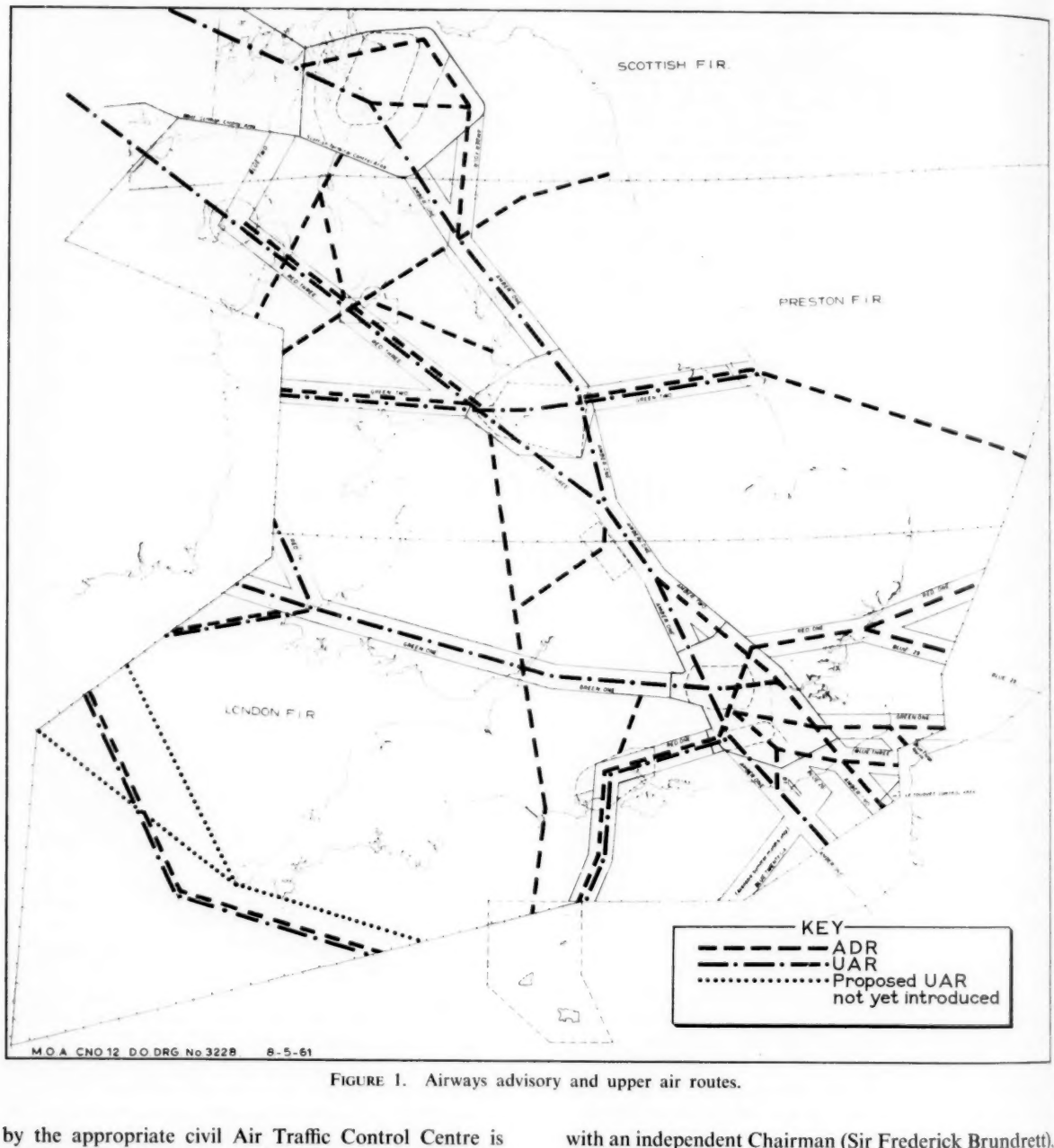

FIGURE 1. Airways advisory and upper air routes.

by the appropriate civil Air Traffic Control Centre is supplemented by a radar monitoring service, provided by civil air traffic control officers from three military long range radar units. The pattern of controlled air space and upper air routes is shown in Fig. 1.

The use of the relatively limited air space of the United Kingdom for the differing interests of civil air transport and non-commercial flying, military operational and training commitments, and research and development flying makes it essential to have a national A.T.C. policy. This is achieved through the medium of the Air Traffic Control Board, composed of representatives of the Ministry of Aviation, the Air Ministry and the Admiralty, with an independent Chairman (Sir Frederick Brundrett), which formulates U.K. A.T.C. policy. Air Traffic Control and military operations will be discussed by another speaker. I shall, therefore, limit myself to stressing the fact that we are already working to a common A.T.C. policy. Considerable thought has been, and is being, given to the best form of joint A.T.C. organisation and to making the most economic and effective use of the facilities now available or planned for air defence, some of the fruits of which can already be seen in the upper air space radar service.

The present airways system has been built up on the requirement to provide safety on the main air transport

routes. During peak periods the attainment of this safety may sometimes be at the expense of expedition in those areas where radar cover is not at present available because of the large separation standards which have to be applied for procedural control. These large separation minima are necessary first, because the internationally adopted navigational aids in general use are not sufficiently precise to guarantee the accuracy of an aireraft's track and reported position within closer limits; second, because of the time taken up with present methods of receiving, processing and displaying the data on which a Controller bases the flow of traffic within his sector.

4. Impending Improvements

To meet the requirement for better navigational aids within the limitations of the revised international standards, additional VOR's (Very High Frequency omni-directional range) are being commisioned as quickly as possible. These may be supplemented by a limited deployment of DME (Distance-measuring equipment), and the provisional VOR/DME Plan is shown in Fig. 2. The existing Air Traffic Control Centres are to be replaced by new centres with adequate capacity to contain the staff, control positions and equipments required both for the next phase in A.T.C., *i.e.* 1964-1969 and for the more sophisticated phase to follow in the 1970's. To serve the period before the new centres are available, improvements are being made to the existing centres. In particular the operations room at the Southern Air Traffic Control Centre is being re-engineered and data transfer techniques, such as closed circuit television and ring strobing of radar blips, are being introduced to ease the Controllers' task.

The value of radar for the control of air traffic has long been recognised in the United Kingdom and a radar system backing up the procedural control system has been evolved. During the next three years, long range radar installations, specially sited and designed for A.T.C. purposes, will be built to provide radar cover over the whole of the airways from 4,000-30,000 ft. Fig. 3 shows the pattern of this radar cover. The information from the radars will be fed into the centres, for processing and display to the control positions which require it. While radar has certain limitations, it has the great advantage of providing the Controller with a dynamic and instantaneous picture of the aircraft under his control. It is an invaluable expediting tool in that experience has shown that separation standards can be safely reduced in plan to a minimum of five miles compared with procedural separation of the order of 40 miles.

By this means more aircraft can be fed into the airways pipe line, faster aircraft can be vectored around slower aircraft and can be climbed and descended through the flight paths of such aircraft, instead of being subjected to delays in the holding stacks. The primary radar system will be complemented with secondary radar so that the Controller will have positive identification of the aircraft fitted with transponder beacons.

With the progressive implementation of the improved navigational aids, extended primary radar cover, secondary radar, and new Air Traffic Control Centres with modernised means of data processing and presentation, it should be possible to make far more efficient use of the available air space.

5. Experience with Jets

During their flights over this country, jet air transports are provided with protection, first along the upper air routes, then as they descend through the airways, until they come under Terminal Area and finally Approach Control. The upper air route system will be developed in the light of experience, probably evolving in the longer term to a form of area control.

Delays to aircraft due to air traffic control are relatively small in the United Kingdom, even at peak periods, and there is no evidence that delays to pure jet traffic are significantly greater than those to propeller aircraft. However, the build-up of jet traffic over the past two years to a stage where almost half the airways traffic is turbojet or turboprop, and more than half of the oceanic traffic is turbojet has necessitated the use of non-optimum flight paths to an increasing extent.

The main A.T.C. problem arises from the fact that, while it is in U.K. controlled air space, 80 per cent of all traffic spends most of its time climbing or descending. It is not easy to separate the problems of A.T.C. arising from increasing traffic from those arising directly from the operation of jet aircraft. The specific problems created by jets are due to their speed differential over other traffic, the limited number of cruising flight levels available at the higher altitudes and the requirement of jets to maintain their high cruising altitudes for as long as possible before optimum descent. Improvements in navigational aids and radar coverage are enabling changes to be made in the geometry of the A.T.C. system which will facilitate jet operations by providing them with discrete climb and descent paths, radar-protected high level holding patterns and improved let-down procedures. Plans have been made for a re-design of the London Terminal Area and adjacent airways, incorporating these improvements, and it is hoped to introduce them progressively during the next few months, when certain difficulties for military, and research and development flying in the area have been overcome.

London-bound jet traffic has so far had a particular problem to contend with through the existence in Airway Green 1, the main airway west of London, of slots reserved for the use of military aircraft. These slots have denied civil aircraft the use of flight levels 200 to 250. This has necessitated either an early descent or a rapid descent when near London, the latter introducing A.T.C. problems and both being operationally undesirable. However, procedures have now been agreed which avoid the necessity for slots.

6. Co-operation with other Countries

Because of the complexity of the Air Traffic Control problem, and the International aspects of it, it is of great importance that full use should be made of work done in other countries, particularly the United States, where in addition to an immense programme of research and development, interesting procedural developments are taking

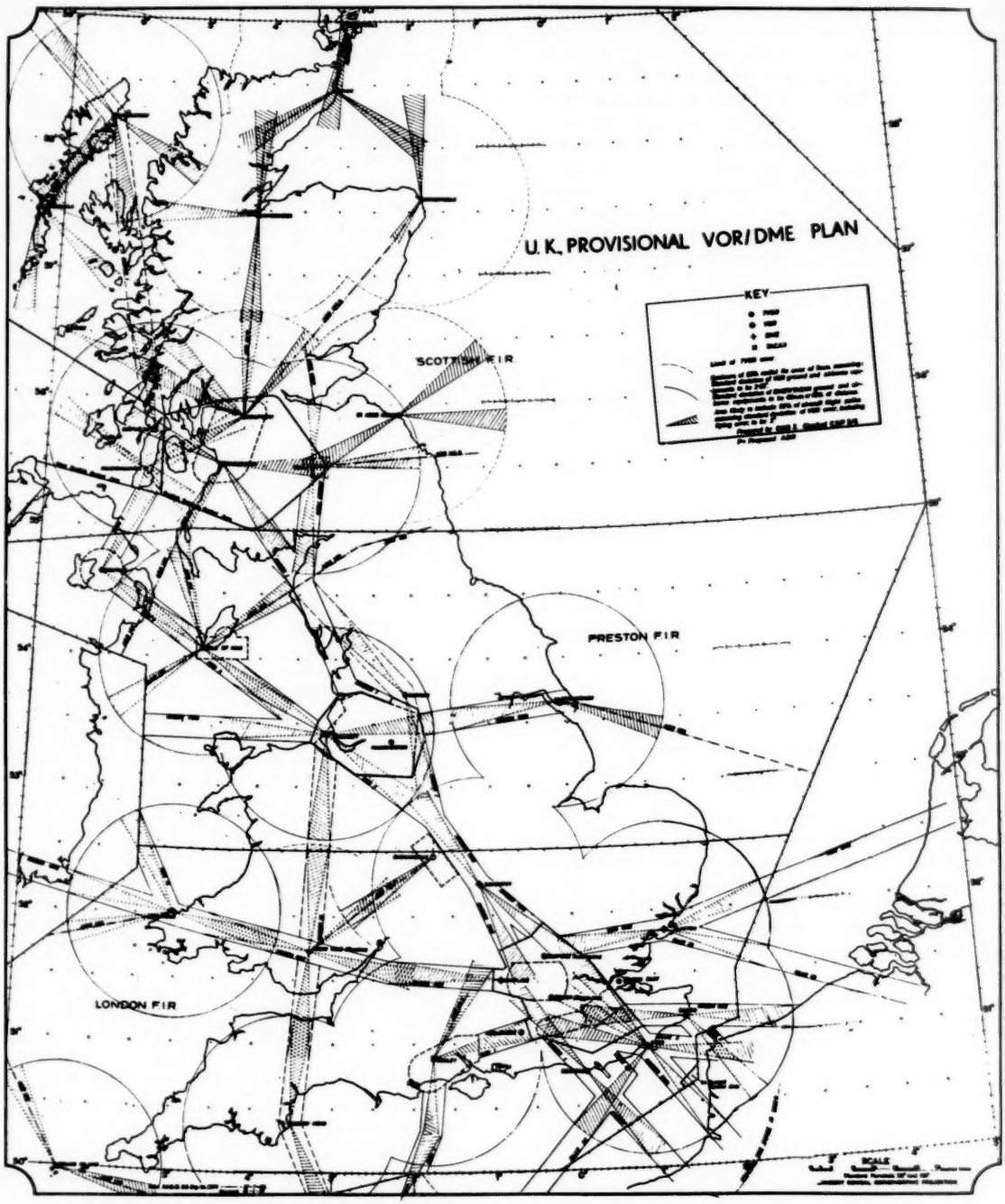

FIGURE 2. United Kingdom Provisional VOR/DME Plan.

place. Particular interest is being taken in the Operation Path Finder Programme for positive area control in all weather conditions which has been introduced in the Indianapolis-Chicago Area between 24,000 and 35,000 ft. It is interesting to note that all U.S. registered jet civil air liners are required to be equipped with radar transponders and that extension of this requirement to all foreign jet operators over the U.S. air space is under consideration. This is an essential development with any A.T.C. system in which radar forms an integral part, and a similar requirement is to be introduced in this country, starting with the upper air space, in the very near future.

Collaboration with the United States is facilitated by the Missions which have been exchanged between the

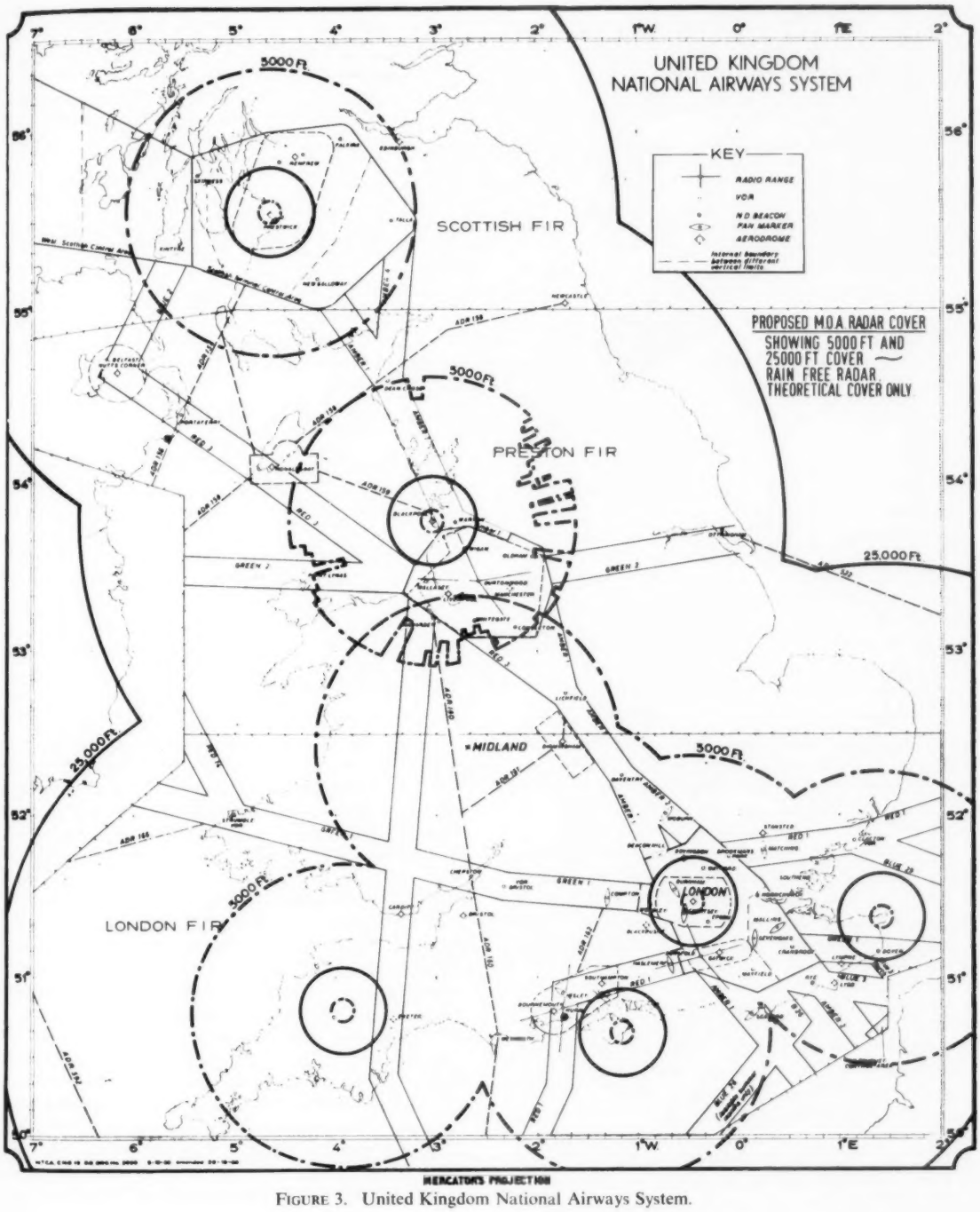

FIGURE 3. United Kingdom National Airways System.

Ministry of Aviation and the Federal Aviation Agency with the express purpose of fostering co-operation in the development of air navigation, air traffic control, and communications systems. Particular fields of co-operation include a study of A.T.C. problems in the North Atlantic area, development and evaluation of long range navigation aids, the study of requirements for and the development of compatible systems of short and long range automatic air/ground data links, and arrangements for an evaluation by the Federal Aviation Agency of the automatic landing system developed by the Blind Landing Experimental Unit.

Another activity, which is of great importance for air traffic control in Europe, is the Co-ordination of

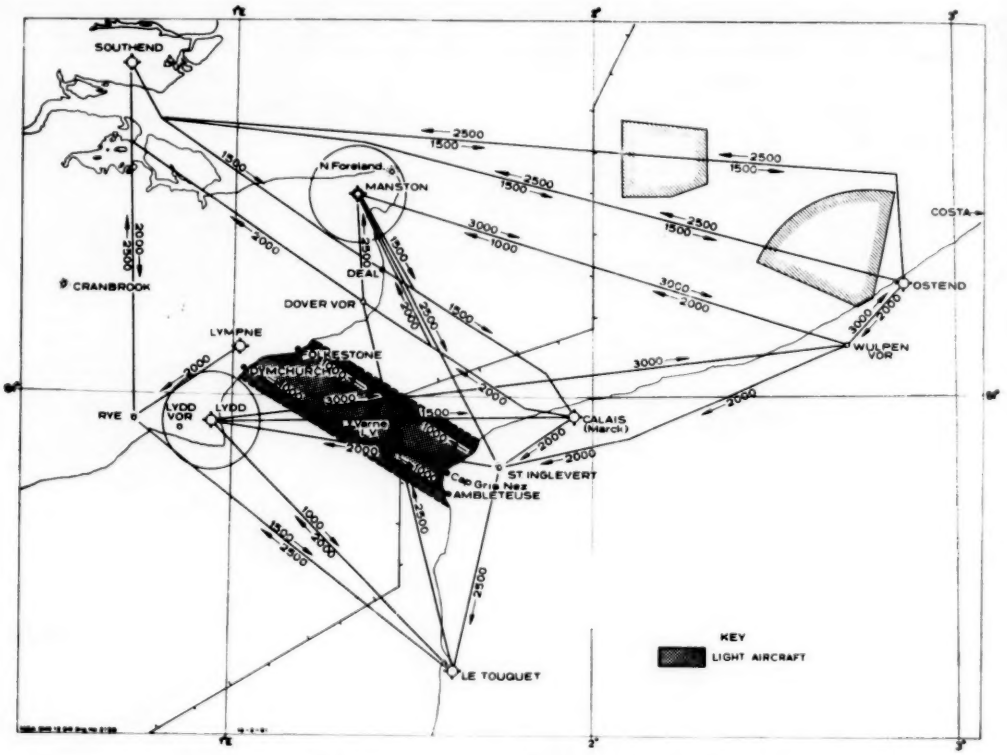

FIGURE 4. Low Level Cross-Channel Routes Scheme for 1961 season.

European Airspace Committee. This Committee has achieved a great deal towards ensuring effective civil and military collaboration and has been especially valuable in facilitating the large scale introduction of jet air transport in the upper air spaces over Europe. It was from the work of the Committee in this field that the idea of a Eurocontrol Agency, which is to control the upper air space of Western Europe, including the United Kingdom, on a supra national basis was first conceived. The concept of Eurocontrol is to be dealt with in another paper.

7. Special Problems of A.T.C.

The North Atlantic at high level and the English Channel at low level pose special problems to Air Traffic Control. As they will be dealt with more fully in later papers, they are mentioned only briefly here. To take first the North Atlantic, there is a pressing need to reduce the very large separation standards which have to be applied to this area, and so to lessen the number of occasions on which non-optimum routes and heights have to be allocated. The United Kingdom is co-operating with the Americans in studies with the objective of defining requirements to enable these separation standards to be reduced. A number of interesting approaches to the various problems being pursued include the development and evaluation of British and American long range navigational systems, better communications, and an extensive programme of experimental work, making use of the Apollo computer, which is to be installed at Prestwick next month. Turning now from the vastness of the North Atlantic to the extremely confined air space between the United Kingdom and Continental channel aerodromes, the car ferry and coach/air services have led to a great increase in the intensity of low level operations which are continuing to build up at a rate of 15-20 per cent each year and already approach a peak of 900 movements a day. This activity takes place at 3,000 ft. and below in the flight information region where it is not at present subject to air traffic control and, since there is the ordinary airways network above the low level area, there is no room for expansion upwards.

Each year, after consultation with the Operators and the adjacent States concerned, a scheme is produced which is designed, as far as practicable, to separate aircraft by track and height (Fig. 4). This year, corridors are being provided in the route system for private and military movements to segregate them from transport operations. These arrangements provide the maximum safety possible with existing facilities, but studies are now being made of traffic flow patterns as a basis for developing a more sophisticated type of control system for this area, with its own special brand of A.T.C. problems.

8. Conclusion

In this short paper I have been able to touch only briefly on a number of important matters, but I have every

reason to suppose they will be dealt with more fully in subsequent papers. What I have said, however, has, I hope, shown we appreciate that increasing traffic and aircraft performance must be matched by progressive improvement in the operational environment. We believe the A.T.C. system should evolve steadily towards the ultimate goal of enabling *all* users of the air space to fly safely with the absolute minimum of restriction. This is a complex and challenging task in which those who fly and operate aircraft, industry and the Ministry all have their parts to play.

Responsibilities of the Individual Air Traffic Control Officer

BY

ARNOLD FIELD, A.R.Ae.S.

(*Master of the Guild of Air Traffic Control Officers*)

THE Oxford Dictionary defines the word responsible as, "liable to be called to account; of good credit or position; trustworthy;" this you will agree is quite a formidable definition.

Therefore, I have assumed the title of this paper to indicate that I should try to explain the abstract effects of this definition upon the individual Air Traffic Control Officer, rather than detail a list of the many and varied duties for which he is responsible.

In view of this approach I do not intend to detail the present day air traffic control system but to indicate the atmosphere within which the air traffic officer is required to apply his art of providing a safe, orderly and expeditious flow of air traffic. Before filling in this background I should like to make one general observation which I believe forms the foundation of the individual officer's approach to air traffic control. I refer to the mental ability to be able to exclude from the mind all matters which are not relevant to the issue of the moment. It has been stated, prosaically perhaps, that severe emotion and frustration are not compatible with sound judgment and good reaction. This is true whether you are piloting an aircraft, driving an express train or, in a more general manner driving a car. However, professionally this is one of the most difficult things an individual can be asked to do—to isolate his emotional mechanism from his judgment.

An air traffic control officer must be able to do this, otherwise he would be a menace to the profession he seeks to serve.

Occupational stress and its associated fatiguing of the mental processes is in general confined to those employments wherein considerable responsibility coupled with heavy work-load relies to a large extent on the adequacy of human resources, and where that responsibility is to human life, society demands that all reasonable steps should be taken to ensure the adequacy of the human resources involved. It is therefore surprising that little or no specialist research has yet been undertaken into the adequacy of the human controller. Airline operators are quite understandably demanding that more aircraft be handled more expeditiously by the control service, without, of course, prejudice to safety. At the same time aircraft are flying faster, they are becoming more costly to operate, are carrying more passengers and are less able to avoid collisions themselves. On the ground extensive radar systems and expensive computers are planned for the future. Clearly at some stage in this rapid development, detailed attention will have to be given to the human core about whom all this expenditure and responsibility is spreading.

In the absence of clinical analysis A.T.C. stress fatigue is extremely difficult to classify and I can therefore only define it in so far as I am aware that it exists, that is by knowledge of outward physical and mental symptoms either experienced or reported. From this experience stress fatigue appears to fall broadly into three main groups:

First deterioration, as evidenced by a fall off in skill and timing, coupled with an unconscious willingness to accept a lower standard of accuracy of performance. This is often manifested by concentration on one aspect of the problem, to the neglect of other equally important aspects. This is probably the most dangerous form of manifestation in that it could be a direct threat to safety. Also, it is the most difficult to isolate because it can affect experienced controllers and newcomers alike. Evidence exists of A.T.C. incidents involving inexplicable human error, which one day may be attributed to this category.

The second category is possibly less dangerous in that it can be more easily detected, at least by the individual. It is also the most common form. The symptoms are a growing anxiety complex, which sometimes cannot be suppressed by inward reasoning. It can occur when a controller is aware of a very complex traffic situation developing at such a rate that he doubts his ability to assimilate it mentally in time to detect and avoid conflicts. This form of mental fatigue is likely to increase with the growing demands made by the more advanced aircraft of the present era. There appears to be no real cure other than a release from heavy duty until confidence is restored.

The third category is that where a controller, after

long exposure to busy and complex traffic situations over a number of years, feels totally unable to continue at the pace. Evidence in this category is, however, not very conclusive as individuals re-act differently and a great deal more needs to be known before the requirements of the service and the individual can be equitably met.

In considering the art of the application of air traffic control it is essential to consider the basic requirements upon which the control of air traffic depends. They are:

(*i*) The ability of the pilot in command of an aircraft to be able to determine his position in relation to the earth's surface.

(*ii*) A method of communication of information between the pilot and the controller.

(*iii*) By accepting information from the pilot over the communications channel; for the controller to apply his art of separating aircraft either in height, time or geographical position.

As I have stated earlier in applying the foregoing factors, it is necessary to assume the existence of an air traffic control system either in the form of a loose recovery service in and around airfields or a more complex service such as the United Kingdom Airways system.

The formula is, however, in itself largely passive and requires the participation of the control officer to bring it into an active state. In this respect it is interesting to consider how this human computer receives the information he requires to apply these basic facts to the system within which he operates.

Aurally he may receive information by radio in headphones or through a loudspeaker, by telephone, by word of mouth from other controllers and by such noise-making devices as bells and buzzers.

Visually, information may reach him from direct observation of aircraft, from a radar display, from a television display, from printed messages, from written information, from maps and charts, from instruments such as clocks and D/F pointers, from lights steady or flashing or even from the use of differing colours. It is by no means unusual for information from these sources to be received simultaneously in varying combinations; the controller is required to assimilate this intelligence, store it in his memory, if required and, what is more important, recognise the order of priority of this intelligence.

There is another method of assimilation of intelligence which occurs primarily at Air Traffic Control Centres where Sectors are usually manned by an Airways Controller and an Assistant. It is one of the responsibilities of the Assistant to prepare estimates for his Airways Controller; these estimates are written on strips of paper which are then inserted in heavy rubber holders and where one of these estimates has been wrongly calculated, the Airways Controller raps his Assistant smartly on the head with the paper strip suitably encased in its rubber holder—no words are exchanged and this we call D.I.A. 'Direct Intelligence Assimilation,' for assimilation is almost instantaneous and reaction equally so.

Having assimilated this information in its varying forms the application of it for control purposes depends upon a number of factors among which are, a sound knowledge of aircraft speeds, manoeuvrability and performance, wind and weather conditions and an ability to assess the action needed to achieve the desired pattern of aircraft paths in space. In this profession of high speed, three-dimensional chess, a wrong move might have disastrous consequences for many. Quick reaction is not enough—the reaction must also be the correct one for the circumstances. Experience of past situations is valuable but the mistakes made in gaining experience cannot be afforded. Even in a situation not previously experienced, a controller's failure to take the correct action can result at best in delays, at worst in disaster. This need for speedy reaction, sound judgment, the ability not to panic in a critical situation, combined with a good understanding of space and time, you will recognise as qualities which are required both by controller and air crew. It is therefore not surprising that the majority of controllers are recruited from either civil or military air crew, for it seems logical that a man who is required to issue instructions to pilots on the conduct of their flights should himself have flown as a pilot or crew member.

This, then, is the abstract background of air traffic control; there is much in the general description which could usefully be filled in but the time available prevents me from doing so. I should however like to make one or two observations on this pen portrait.

First in regard to A.T.C. stress fatigue, to examine possible remedies one must first look at probable causes. There is little doubt that the primary cause is the very nature of the work, details of which are not in the context of this paper but which will be discussed during this session. In addition to the primary cause there are subsidiary causes common to other employments and to which the solution is comparatively easy. I refer to environmental considerations.

For a solution to the primary cause of stress it is reasonable to hope that the answer can be found in the advent of sophisticated "black boxes" designed to assist in removing much of the stereotyped data and liaisons required by present techniques. It is important when considering what these "black boxes" should be, that it is not just making decisions that fatigues, for air traffic control officers are selected and trained to be men of decision. What does fatigue is the amount of work involved in arriving at an executive instruction and the considerable mental effort involved in seeing a dynamic picture over long periods, for A.T.C.O.s are still required to visualise a three-dimensional picture from a two-dimensional display.

The solution to the subsidiary causes is largely one of commonsense and economics; they concern such matters as noise, air conditioning, lighting, furniture, staff amenities, and so on. It is fair to say that a great deal has been achieved in this direction but it is also important to stress that these items can, and do, have a marked effect upon fatigue. For example, while the carpet on the floor at one of our major air traffic control units may give rise to a few wry smiles its contributions towards the problems I have endeavoured to outline far outweighs its cost in terms of pure economics.

Recruitment and training are two further items which I should like to mention. Earlier I indicated that the basic qualities required by air crew members were also those essential to an A.T.C.O. In other words both professions are seeking the same material from which to fashion their service. Adequate conditions of service are quite properly the province of Staff Associations. I should, however, like to make the observation that there should be a relationship between the two professions if the air traffic control service is to continue to attract young men of the right type.

Basic training is, in general, done effectively and efficiently but it is essential to remember that A.T.C. training, be it Radar, Airways, or the many aspects of airport control is merely the jig upon which the finished article will be fashioned. The Controller may be better than his training but he ought never to be worse. Training should therefore set out to achieve a high minimum standard and advanced training should form an essential part of a Controller's life.

It is possible that in the next decade A.T.C. will progress from an Art to a Science, but during this period of progression much remains to be done to assist the human link in his task of expediting safely these highly complicated capsules of aluminium from one point on the earth's surface to another.

A.T.C. and the Civil Airline Operator

BY

A. E. SLOCOMBE, A.R.Ae.S.
(Superintendent, Air Traffic Services, B.E.A.)

1. Introduction

This paper deals primarily with Air Traffic Control in the European region and does not refer to problems specific to other areas. Nevertheless, most of these problems are common to all regions and differ only in degree. Their solution depends upon the existence of a properly organised and equipped Air Traffic Control Service and there is now world-wide recognition by users and providers alike that such a service is an essential element in the ordered development of aviation.

What does the civil airline operator want from Air Traffic Control? He wants protection from collision with the minimum of restriction but with the maintenance of an orderly traffic flow. For this reason airlines have become deeply involved in the A.T.C. problem both nationally and internationally and, although they do not pretend to be A.T.C. planning experts, must maintain a close watch on all proposals and developments. It is essential that operators be in a position to discuss A.T.C. plans with the authorities before they become finalised. In this connection an airline will view the procedures against the whole background of A.T.C. development throughout his network. He must take into consideration their possible adoption by other States who may try to introduce them without comparable organisation and facilities.

2. I.A.T.A. Technical Activity

Except with its national administration or in respect of an incident directly affecting one of its aircraft, an airline does not normally approach a State direct on A.T.C. matters. Understandably States do not usually want the opinion of one airline alone and operators' views are co-ordinated by I.A.T.A.

The guiding body on all technical and operational matters is the I.A.T.A. Technical Committee composed of senior operations or engineering executives from twenty-one airlines. I.A.T.A. Technical Policy developed at Annual Technical Conferences or by special groups must be approved by this Committee. The seriousness with which airlines regard A.T.C. is illustrated by the fact that in fourteen Annual Technical Conferences, on only two occasions has it not been a major item on the agenda.

Also, I.A.T.A. has now formed a small Air Traffic Services Study Group to keep a watch on new developments and to develop I.A.T.A. policy accordingly. The Group has only been in existence a short time but promises well, and the attendance by administrations, including the Ministry of Aviation and the F.A.A. is much appreciated.

3. Airlines and other Users

Airlines are firm believers that within the air space used by them, there can be no question of continued reliance on pilot lookout to avoid collision. In our interpretation this means control by a ground authority of all movements within this air space whether flying in VMC or IMC. The A.T.C. service should, therefore, be organised on this basis.

However, this does not mean that airlines wish to impose unnecessary restriction on private, business, or military aviation. All we require is that our aircraft are protected from collision throughout all phases of flight. The airline route network, particularly in the more developed areas, should not change greatly and expansion of the lateral dimensions of controlled air space will be primarily for A.T.C. considerations or because of new requirements by other users. The vertical limits on the other hand are going through a considerable change. The introduction in ever increasing numbers of jet aircraft flying at the higher altitudes has increased the civil/military problem, but at the same time provides the

possibility of releasing controlled air space at the lower levels.

In so far as private and club flying is concerned there should be, even in this small country, room for aircraft not equipped with radio to enjoy a good deal of freedom without interference to other traffic, although the time must surely come when all such aircraft must be capable of communicating with A.T.C. Business aircraft are in rather a different category. To fulfil the function for which they are designed it would seem essential that they have the minimum communications and navigational equipment to make them capable of operating in controlled air space without endangering or disrupting air transport movements.

With regard to gliding, it is unfortunate that, in this country, all the best spots seem to lie along our civil air routes. Although we have been free of incidents here, my airline has had some trouble with gliders in several places in Europe and cannot, therefore, treat the problem lightly.

To sum up, therefore, A.T.C. considerations should not prevent private and business flying from developing in this country hand in hand with Air Transport, while maintaining adequate safety standards. In the Civil Aircraft Control Advisory Committee the Ministry has provided the machinery for free and frank discussion between the various civil interests.

4. Civil/Military Co-ordination

The co-ordination of civil and military traffic remains the big problem and is so complex that its proportions must first be reduced by segregation as far as is acceptable to both interests. Where segregation is not practicable then the traffic must be properly co-ordinated. Progress in the United Kingdom in this respect is encouraging, with such measures as the radar service in the upper air space, standardisation of procedures and integration of training programmes.

In Europe generally, similar moves are taking place but, particularly in Northern Europe, the problem in some respects is rather more difficult than in the United Kingdom and makes it necessary to develop more swiftly towards an integrated civil/military system on an area control basis. However, the problems of controlling considerable numbers of aircraft crossing and converging within a large area, are all so immensely difficult that a full area control system must be many years away.

The airlines welcome the concept of Eurocontrol and I.A.T.A. has been privileged to take part in many of the technical discussions leading to its formation. It is a pity that it could not have been a truly civil/military agency, but it seems that provision is made for full inter-departmental discussion in all phases of planning. It is to be hoped that it will not be too long before the practical results of the work done so far will become apparent and that non-technical and political aspects will not delay its introduction as a functioning concern.

5. Control of VFR Traffic

In general the measures being taken to improve Air Traffic Control, both here and in Europe, seem to be the right ones. However, even small improvements take far too long and in the meantime the existing systems are expected to cope with steadily increasing demands. Not only this, the A.T.C. service does not even meet current requirements since, in order to increase the capacity of the system, reliance is placed to far too great a degree on traffic going VFR (Visual Flight Rules) or carrying out VMC clearances. Possibly the penalties of going IFR (Instrument Flight Rules) may not be as great as imagined, particularly as an orderly flow of traffic can be more easily maintained if all aircraft are not only known to A.T.C. but follow common procedures. There are, however, still some areas where application of full IFR rules would result in inordinate delays, with little or no improvement in safety because the systems would very quickly become over-loaded.

As a move towards full control I.A.T.A. airlines now file and maintain IFR flight plans in certain areas, including Europe, and irrespective of weather conditions. This will not, of course, eliminate the possibility of IFR/VFR incidents until States take action to ensure that other aircraft do the same.

In the United Kingdom the introduction of IFR procedures in the London and Manchester Control Zones and on airways is welcomed. Again, however, VMC climbs and descents are permissible, although B.E.A. and certain other airlines do not accept this procedure within the London and Manchester Terminal Control Areas where good radar control is available. The sooner that this procedure can be dispensed with the better.

6. "Air Misses"

One means of assessing A.T.C. efficiency is through captains' voyage reports. Also, B.E.A. has long supported the "Air Miss" reporting procedure and an "Air Miss" involving a B.E.A. aircraft is treated as a reportable accident and receives the attention of the airline's Air Safety Committee. The number of air misses has decreased considerably in the past year or two but this reduction must not be viewed with complacency since some reports are still of a most serious character. The greatest attention must continue to be paid not only to the incident itself but to the basic causes, so that remedial action can be taken as quickly as possible. Confliction between IFR and VFR traffic still represents a high proportion of air miss reports.

7. Need to raise A.T.C. Capacity

An aspect of A.T.C. which is assuming some importance is the runway capacity. There will be an increasing need to achieve a high movement rate sustainable over several hours with sufficient in reserve to absorb traffic peaks. This requirement for a high sustained runway capacity will be necessary at Heathrow within the next two or three years. The present landing capacity using one runway is 18–20 per hour, rising for short favourable periods to 25. B.E.A.'s estimates of the total traffic on a typical summer Saturday, and by no means a peak day, show that next year the single runway landing capacity will be required for a continuous period of 5 hours and

by 1964 for 14 hours. Ways and means of making fuller use of the parallel runways for landings will, therefore, have to be found.

A.T.C. has a big influence on the overall productivity of the airport and consequently its financial self sufficiency. The runway capacity will usually be more limiting than the capacity of buildings, aprons, and car parks, which are more capable of continuing development. It is important that all should be fully utilised so that airport and airline costs are kept at a reasonable level.

Clearly radar is playing an increasing part in raising air space capacity. The airlines fully support the use of radar provided that the equipment is reliable, the controllers properly trained and there is a satisfactory procedural system to fall back on. The United Kingdom has been a pioneer in the use of radar for A.T.C. and the excellence of its radar service is well known. Other countries are similarly doing well but airlines must try to satisfy themselves that the equipment and training of controllers will allow the reduced separation minima to be applied with safety. Unfortunately, unlike secondary radar, there exists for primary radar no international standardisation on the system characteristics and the technical specifications for the equipment, except for GCA (Ground Controlled Approach).

Airlines are also watching the introduction of automation into A.T.C. units with interest. They are not really directly concerned unless at some later stage new airborne equipment or changes in A.T.C. or flight planning procedures are involved. Nevertheless, anything that will increase the capacity of the system and, at the same time, relieve the pressures on controllers, receives our close attention.

Heavy demands are being made on controllers who in some places have to carry out their exacting tasks with the most rudimentary facilities and with small hope of any improvement. The keenness displayed in some countries is surprising when one learns of the poor conditions of service of controllers and the very low salaries they receive. These conditions are beginning to improve but far too slowly, since it is essential to attract the right sort of people and to ensure that they are properly trained. The raising of A.T.C. personnel and training standards, where deficient, and the resultant improvement in status, would, more than anything else, bring about a general improvement in the A.T.C. service.

8. New Air Transport Developments

Finally, a word on helicopter and supersonic air transport. The extent of helicopter air transport operations in the United Kingdom cannot yet be determined but the build up is likely to be fairly slow and initially will not involve full instrument operations. The main impact will, of course, be within terminal areas and at airports and provide a problem of separation from fixed-wing aircraft on final approach and during take-off. If backward take-off techniques are used this may affect the A.T.C. capacity at heliports. The extent to which it will be necessary to introduce control *en route* at the lower levels, it is too early to say but this does not mean that the same procedures or separation minima will apply. Nevertheless, safety standards must be equivalent to those required for fixed-wing aircraft.

With regard to supersonic aircraft, it is essential that they should be capable of fitting into the A.T.C. system without disruption to other traffic. The effect of the introduction of aircraft requiring procedures fundamentally different from those established for the majority will be to reduce the system capacity out of all proportion to the number of new aircraft involved. It is important that the approach speed approximates to that of existing aircraft, since a marked difference in speed between succeeding aircraft seriously affects runway capacity. Still, the introduction of turboprop and turbojet aircraft each in turn gave rise to fears that the A.T.C. system would be severely disrupted. This has not happened so it is to be hoped that the new problems will also prove capable of solution.

Air Traffic Control and Military Operations

BY

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THE BASIC objective of air traffic control in military flying is, of course, the same as in any other flying; to enable all aircraft to fly safely throughout each flight with the maximum freedom to attain their purpose efficiently. In practice, this necessarily involves the imposition of conditions and restrictions, and it is one of the main aims in the development of air traffic services to increase both the safety and flexibility of aircraft operation with the minimum restrictions. In progressing this we fully recognise the needs of civil aviation and, contrary to some public misconceptions of civil/military conflict in air traffic control, a joint approach is made at all levels to resolve A.T.C. requirements.

A great deal of military flying is quite compatible with an approach to the problem similar to that required by modern commercial operations. This includes transport and transit flying over regular routes and the recovery phase of most flights, even where their primary purpose may be quite different. There is, nevertheless, a large amount which needs an operational flexibility not compatible with fixed routes and for which purely procedural control methods are not suited.

This is flying of a random nature undertaken primarily for training purposes. Exercises are necessary in operational squadrons as well as in the flying training organisation for the purpose of aircraft handling and practising individual crew skills, and in these the route and precise position of the aircraft is not a main factor in the task itself. Test flying, both within the Royal Air Force and the Research and Development organisation of the Ministry of Aviation, is somewhat similar in relation to the desired air traffic control facilities.

It is always, of course, desirable to segregate such aircraft to areas where other activity is very slight, although with the present performance of even training aircraft the area needed is large compared with the air space available, bearing in mind the increasing requirements of other operators. It is a current problem, therefore, to devise improved methods of removing the risk of collision from aircraft on flights which are not susceptible to second-by-second control instructions, and thereby to increase the efficiency of training and testing.

In mentioning segregation, I want to emphasise strongly that all military flying gives full recognition to controlled air space regulations. Aircraft flying Airways do so in conformity with civil procedures, and aircraft entering controlled air space are required to do so strictly in accordance with standard regulations for radar or procedural clearance. The only exception is that on occasional major defence exercises variations may be agreed with the civil authorities and published in advance.

Between scheduled transport operations, and flying training and test flying, there is a large amount of military flying which is not on regular routes but which does, when airborne, adhere to routes which can be made known a short time in advance. These include navigation and operational training exercises of various kinds which can accept a wide range of control instructions without undue interference with the aim of the flight. Provided their scope is not made too limited by permanent extraneous restrictions, they are quite compatible with methods of positive control.

A particular problem in the limited air space available is the provision of climb and descent paths to and from the upper air space. It is a common requirement of all operations that whenever practicable climb and descent should be uninterrupted and in accordance with the operating procedures for the aircraft concerned. This applies particularly to short endurance aircraft, the normal Hunter sortie, for example, being well under an hour and on return, using the most economical direct descent path, the aircraft has only a few minutes fuel remaining for an over-shoot or diversion to a landing strip within a few miles of base. There is consequently practically no fuel available for extra procedures once the aircraft is committed to descend. When a number of airfields are adjacent to each other this presents a difficult problem. Although by no means peculiar to military flying, it is one which frequently involves Service airfields in this country. These are often close to each other for various reasons, not least because there is a deliberate tendency in all R.A.F. deployment to use military airfields away from centres of intense civil activity and controlled air space wherever possible. This climb and descent problem has been overcome to a considerable extent by careful integration of airfield patterns and by control under a common authority in areas of potential conflict. It has not been solved and is receiving intensive study with a view to increased flexibility and fewer restrictions.

In a determined effort to minimise the risk of incidents involving military aircraft the Royal Air Force is making increasing use of existing radar cover to exercise positive control of a great deal of military flying. It is intended to extend progressively the cover available to A.T.C. and to extend the capacity and capabilities of the control organisation. A start has been made on the joint use of such facilities for the benefit of both civil and military aircraft. This development is likely to be greatly enhanced in the future by relaying information from new air defence radars to the main joint Air Traffic Control Centres.

Although the R.A.F. is making good use now of radar as an air traffic control tool, we are fully aware that radar must be supplemented by other navigation and identification, as well as communication, equipment to meet future needs. Radar cover is the basis of any air traffic control system for the foreseeable future but we are also anxious to consider carefully all technical developments in both ground and airborne equipment which give promise of a more efficient organisation. We believe that for the great amount of military flying which is compatible with positive control it should be possible to make common future use, with civil operators, of all air space safely and efficiently. The random flying, of which there is a good deal in the Air Force, is not susceptible to the same sort of positive control and in making arrangements for training to achieve its objective the Royal Air Force will continue to act in the closest co-ordination with the civil authorities in the Ministry of Aviation.

The Application of Automatic Techniques to the Problem of A.T.C.

BY

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THE WORDS "automatic techniques" used in the title of this paper are interpreted as applying to all aspects of the Air Traffic Control complex, in which the latest electronic and electromechanical developments and techniques might prove beneficial. Navigational capability, communications efficiency, data processing, planning and dynamic displays, and conflict detection can all be improved, for example, by equipment incorporating various degrees of automation. While it is easy to list such improvements, it is much more difficult to relate their value specifically to a particular Air Traffic Control problem at a particular centre, and to recommend in which respects money or effort expended by the Government responsible would bring them the greatest or most immediate benefit. In fact, experience shows that each case differs and requires special study and consideration so that any difficulties currently existing or foreseen can be expressed in terms that facilitate rational engineering solutions.

One sometimes hears the opinion voiced that the current Air Traffic Control system works pretty well, that changing from well-tried manual methods of control to expensive, complicated black-box dominated systems is both unnecessary and undesirable; if Governments will only provide better radar cover, more controllers, more displays and more communications, all will be well. To my mind, such an attitude ignores the facts and imperils the future. Air transport as a whole simply cannot develop as it should until we have A.T.C. organisations capable of providing service to all potential air space users within their sphere. If we are to avoid in future undesirable recourse to various forms of segregation and restriction, we must provide more flexibility and efficiency in air space utilisation, so that civil transport operations, military operations, executive, private and all kinds of flying can be accommodated and permitted to expand. They should, in my opinion, be allowed reasonable operating freedom within the Law, but not accorded (as some suggest) a degree of licence that could cause operational anarchy. The size, complexity and cost of computers required to deal with such a situation would be enormous. (I am assuming that a suitably co-ordinated civil/military A.T.C. service is now regarded as both inevitable and desirable.) Obviously this would necessitate some airborne equipment in aircraft that, for economic and technical reasons, have so far found fitting it impossible, but if a sufficiently serious effort were made I believe some acceptable solution might well emerge. Miniaturised data transmitting equipment has, after all, been developed for other purposes. The problems of non co-operating aircraft are at present beyond the reach of automation, and must be handled administratively. We in the electronics industry can only offer these private aircraft our sympathy in their difficulties, and our prayers for their safety. Although initially a matter of organising air space, providing facilities and developing procedures, the consequent need for electronic data processing equipment as a result is surely obvious. Action is required at once if the new centres are to be equipped, and controllers trained and ready for this inevitable expansion.

The electronics industry in various countries, particularly perhaps in the United States of America, about which we shall hear from the next speaker, is already developing and supplying a wide variety of operational and experimental equipment for use in Air Traffic Control centres. In order to offer the authorities a service commensurate with that already provided to other users of complex and not inexpensive electronic devices, a manufacturer must become completely versed in what may be termed Air Traffic Control Systems Engineering. The engineer rash enough to venture into this new field must acquire complete knowledge and understanding of the Air Traffic Control process, and be able to distinguish between those activities which are fundamental and those which are merely traditional. He must recognise that however much he may feel disposed on theoretical grounds to criticise current methods, the existing system is a living entity that works successfully and cannot easily tolerate rapid or radical changes. He must understand why any proposals for improvement should be directed at assisting, rather than replacing, the human Air Traffic Controller; in particular, taking care to leave to that gentleman the supervisory and executive functions in which he constitutes both the most flexible, the most reliable and the cheapest computer on the market. Although endeavouring to achieve trouble-free design of equipment, he would be well advised to accept the fact that at some time or other failure is virtually inevitable. Therefore he should incorporate adequate protection in any system against the dangers of serious consequences from component failure. Finally, he should not overlook the fact that although it may be easier administratively to effect an improvement in systems capacity by modernising ground control centres, the airborne component of the Air Traffic Control complex is equally important and at an early stage of the evolutionary process it may prove equally essential to rationalise aircraft operations; in other words, efficient organisation and use of air space are of equal significance in producing the optimum results. It will then be necessary to re-evaluate the effect on Air Traffic Control of

Type of System	Data Transfer	Display Preparation	Display Updating	Conflict Detection	Conflict Resolution	Air / Ground Communication
(a) Fully manual	voice	manual	manual	Controller	Controller	voice etc.
(b) Partly mechanised	teleprinter etc.	"	"	"	"	"
(c) Machine assisted Flight Plan Processing	"	strip printer	"	"	"	"
(d) Semi Automatic	"	"	automatic F/P board	"	"	"
(e) Semi automatic with Conflict Detection	"	"	"	computer	"	"
(f) Fully automatic	"	"	"	"	computer	Data link

FIGURE 1.

more accurate and flexible means of navigation, as well as automatic air/ground communications for rapid exchange of routine data. A.T.C. is, after all, a co-operative service in which the controllers' and the pilots' problems are equally important. Simplifying the one at the expense of the other is no satisfactory answer.

Governments at present, however, are concentrating largely on improving their ground control organisation. Fortunately, with the exception of equipment and procedures concerned with interchange of data between centres, Air Traffic Control ground facilities can be modernised without waiting for international standardisation. Fig. 1 shows the stages in which it appears probable these improvements may evolve in Europe.

If we regard the task of the Air Traffic Controller as a three-phase cycle of (*a*) Prediction, (*b*) Observation and (*c*) Intervention, and the efficiency of a centre (or a controller) as being measured roughly by the speed with which contingencies are resolved, potential sources of improvement can be pinpointed. (A contingency is defined as an occasion on which an infringement of separation criteria has occurred or is about to occur.) It is important that the controller be given flexibility in choice of the solutions he can select to resolve these contingencies. What can we do to help him?

Better data processing (which means acceptance, sorting, storing, calculating and disseminating information), improved communications facilities, better situation displays, assistance in conflict detection and, in general, relief from drudgery, will all help the controller to concentrate on finding quicker and more effective solutions of the complex problems he is often required to resolve. Traffic situation displays must fulfil the controller's needs for overseeing both the planning and executive functions of A.T.C. Although various attempts have been made to eliminate it, the tabular flight progress strip display remains the basic planning element in civil Air Traffic Control and so far as can be foreseen will remain so for a very long time. It is probable that the current manual boards will be replaced by modern methods, such as automatic tabular bays or by alpha numerical character generation on cathode ray tubes or banks of electromechanical indicators, or some entirely new form of tabular display. For the executive function the dynamic display, provided by radar, remains the backbone of Air Traffic Control, particularly in terminal areas. Efforts to provide improved equipment incorporating height discrimination, daylight viewing tubes, target identification and automatic tracking are being made. Secondary radar, too, is going to help enormously, especially if, in addition to identification, it is able to relay altitude data. Nevertheless we must be very careful in our support of extended use of radar that we do not overlook the danger of over-loading radar controllers. Radar separation seems unlikely to be lowered, and there is a finite limit to the number of contingencies a controller can deal with at one time, however rapidly a computer can detect and denote them.

Methods of sequencing inbound aircraft to achieve the optimum landing rate are under investigation, using both analogue and digital techniques. Conflict detection assistance is also available from powerful modern digital computers, but their major value almost certainly lies in their capacity for storing and processing at computer speed, with high reliability and versatility, the truly vast quantities of information required in the larger Air Traffic Control centres. However, the programming effort necessary to introduce these machines into the A.T.C. service is very considerable indeed and knowledge of how to devise A.T.C. programmes efficiently can only be acquired in the hard school of

experience. The importance of certain more mundane items in A.T.C. should not be overlooked. Communications equipment of various kinds, strip printers, and keyboards merit considerable design effort. Attention must be given to human engineering aspects, such as noise reduction and good station design.

Lastly any proposals for improving A.T.C. facilities should be based on the principle of evolutionary implementation and, so far as can be foreseen, involve minimum subsequent equipment redundancy.

Developing new equipment for Air Traffic Control takes a great deal of effort, time and money. There are no text books or specifications that one can consult with any confidence. Before any manufacturer can feel reasonably secure in entering this business the purposes for which new or improved equipment is necessary must be specified, the functions the equipment is expected to perform in a technical sense must be defined and finally, the requirements must be rationalised by efficient systems design. It is important to ensure compatibility both of functions and engineering performance within any new system and, as far as possible, with other systems both existing and planned. In more simple terms, this means developing the ability to supply technically, operationally and economically attractive units or sub-systems that can be effectively combined in a number of ways to meet a variety of operational demands.

We who spend our working days (and occasionally portions of our nights) on the problem are only too well aware of the practical difficulties of improving the Air Traffic Control service and of the tremendous efforts that many Governments such as our own are making in this field. We in industry welcome opportunities to help in this complicated and difficult task, and hope that we will continue to get encouragement from Governments to employ to the full such knowledge, inventiveness and ingenuity as we may possess in seeking more efficient and economical methods of guiding, marshalling and monitoring with safety the ever growing volume of the world's air traffic.

F.A.A. Experience Gained in the Use of Digital Computation

BY

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Introduction

The application of automatic data processing techniques to air traffic control has been espoused by both operational and research and development groups dealing in air traffic control throughout the world. As far back as 1947, in the U.S.A., the Special Study Group, SC-31 of the Radio Technical Commission for Aeronautics suggested that a high degree of automation be applied—including rigid control of all flights and their times of arrival.

The latest group in the U.S.A. which developed a comprehensive plan for automation was the Curtis Group, which set forth in 1957 a scheme of partial automation—of the human controller's functions—leaving him free to carry out the fundamental decisions required for safe and efficient air traffic control.

The current F.A.A. programme for improvement and modernisation of air traffic control is a three-pronged effort each involving the use of automatic data processing.

F.A.A. Experience in the use of Digital Computation.

Approximately five years ago the former C.A.A. launched a programme to utilise general purpose digital computers in the A.T.C. system. They obtained an IBM 650 and a UNIVAC file computer for operational and technical experimentation development and evaluation purposes. One of the first objectives of this project was to relieve *en route* control personnel, insofar as possible, of some of their tedious routine work. The manual processing of raw flight plan data, preparing flight progress strips, and relaying these data to adjacent facilities, were selected as the target areas for the first effort.

After using these computers in the laboratory and live operations to perform these functions, it was decided to install five UNIVAC's and the one IBM 650 in six A.R.T.C.C.'s in the Northeast portion of the U.S.A., where traffic loads are consistently high. Initially, these computers functioned independently in an off-line, punch card type of operation on a 16 hour a day basis. Then, about eighteen months ago they were connected via telegraphic channels into the present day en-line network that uses punched paper tape as terminal input/output storage buffers. They serve today as flight plan processors to prepare flight strips and relay inter-centre data. We commonly refer to this system as the Phase 1 Computer System.

Following the Curtis recommendations the Airways Modernisation Board in 1958 initiated a new advanced computer development programme to extend automation of the A.T.C. system for high density *en route* and transition/terminal areas, called the Data Processing Central Programme. The objectives of this programme extend well beyond the Phase 1 system. It will automate most of the routine controller functions, but still could easily be integrated with contiguous manual A.T.C.

facilities and communicate automatically with SAGE centres. The system is based upon the latest state of the art engineering techniques and retains the flight progress strip mode of operation. The latter keeps it evolutionary from an operational viewpoint, and provides a reliable back-up for reverting to manual operation in case of equipment failure.

The prototype of this system has been delivered to the National Aviation Facilities Experimental Center at Atlantic City, New Jersey, and is now undergoing "debugging" tests. The heart of the system is the A.T.C. Data Processor or Computer Group that uses the solid state computer developed by the Librascope Division of G.P.E. (for the F.A.A.). It is a multiple electronic digital computer system designed to integrate electronic computing with a large magnetic drum storage capacity. This is done in such a manner to permit simultaneous operation of the computer elements, the drum file system, and an input-output buffer system. This was the first digital computer complex designed and built around A.T.C. requirements. It has now had a full year of stringent testing, and has emerged a reliable, new device for implementation of air traffic control.

The D.P.C. has been designed on a functional building block approach to accomplish or include the following:

1. Flight Plan Acceptance, Processing and Distribution.
2. Automatic Updating of Flight Progress Strips.
3. Conflict Prediction, Resolution and Display.
4. Bright Radar Display with Manual Control of Alpha-Numeric Data.
5. Flow Control.
6. Radar Track-While-Scan, including Tracker Driven Alpha Numeric Data Generation.
7. Sequencing Control.
8. Radar Beacon (SSR) Data Processing.
9. Scramble Corridor and Return-To-Base Conflict Prediction, Resolution and Display.

This building block design allows us to implement portions of the system without destroying the overall system design.

A third approach involves the careful study and an extensive evaluation to determine the feasibility of integrating our A.T.C. functions with those of the Air Defence Command in the SAGE Computer System, and utilising techniques and equipment designed for air defence for air traffic control. We have been pursuing this programme for several years and now have a full experiment, about to become test operational under a contract with the MITRE Corporation.

This environment, called SATIN, is centred around the FSQ–7 computer and employs all the communication, radar and data transfer capabilities of the Experimental SAGE Sector at Lexington, Massachusetts. This project encompasses a comprehensive attempt to test some of our concepts for electronic pictorial controller displays. Also, an operational test of a SAGE centre programmed for A.T.C. display will be carried out the latter part of this year at Ft. Lee, Virginia.

Our findings and opinions on digital computation for air traffic control have been gained principally from working with these three digital computer complexes. Almost immediately we encountered the problem of integrating the human, psychologically and functionally, with the computer equipments. The first factor is usually manifested in terms of controller resistance to the changes involved or lack of confidence in the machines. Normally this difficulty is solved to a great extent after actual experience with the computers. We have taken great care to ensure that operational personnel are familiar with our current developments, and participate in the design of the technical equipment. All three attacks on the problem of modernisation of air traffic control facilities contain the inherent concept that human traffic controllers will continue to make the fundamental traffic controller decisions—and the automated equipment is designed to assist the controllers.

In the staffing of the Research and Development Bureau of the F.A.A., we recruited young controllers from the field, and taught them to become digital computer programmers. Controllers are placed in all elements of the research and development operations: planning, system engineering, equipment development and system testing. In an operation such as A.T.C. where safety is of over-riding importance to any other aspect, we believe that those with operational responsibility must first be partners in the research and development cycle, and later have the final say on the safety of the equipment developed. As an example of the functional aspect of the problem, let us discuss the manual inputs supplied to the computer by the human operator. Obviously, the system is no better than the data it is supplied, and it is dependent on the flight plan input device operator for the appropriate basic information. Since man does not speak in binary code, and is prone to omission and transposition errors, we must go to great lengths in assisting him to readily provide error-free input messages. Two approaches are being used by F.A.A. for entering complete flight plans. They are: (1) an electronic keyboard device called FLIDEN, an acronym for "Flight Data Entry Device" which has a CRT display for the operator to check his composition along with excellent error correction capabilities; and (2) several modified punched paper tape programmatic machines, *e.g.* the Remington Rand UNIVAC Synchro-tape Typewriter, the Teletype Corporation 28 ASR format generator, and the IBM Flexowriter which provide hard copy and limited error correction capability. The same kind of problem exists for flight plan updating which normally requires input messages entered at the control sectors. We have developed several types of controller-input keyboards for this function with the aid of the human factors engineers.

Both types of input devices require some means for the operator to check his data prior to transmission. It is desirable that all feasible electronic interlocks be incorporated that will prohibit the operator from being able to even enter predetermined invalid entries. Programmatic devices serve as a good aid to the operator since he can mentally ignore things such as system functional codes and some format constraints, while encoding his message. All these equipments mentioned perform satisfactorily; nevertheless we are continuing to

work vigorously in this area because, in our opinion, this is one of the very critical links in the chain.

Matching the computer to the controller is one of the many reasons that prompted us to establish our extensive Test and Experimentation Center at Atlantic City, New Jersey. We have found it profitable to carry out real time experiments in air traffic control—and are able to resolve many questions, and find solutions to many problèms to which theoretical processes have not yet yielded hard answers.

We are proud of this fine, rapidly maturing facility, and have great confidence in its role in our research and development programme. We take every precaution to keep the Test Center environment as realistic as possible and utilise experienced operations personnel to supervise and operate these A.T.C. experiments.

The next subject area is internal computer programming. I cannot over-emphasise its importance. It is a very flexible part of system design and it can be used to accomplish many of those system requirements that are difficult to put into hardware, or those so small that they do not justify the extra black box. Its very flexibility can easily lead one into adding new functions or variations in sub-routines to the point of over-loading computer capacity. Our experience indicates that strict discipline should be maintained on the development and modification of internal computer programmes.

The compatibility and interactions between the internal computer programmes and the ancillary equipment is an area of prime importance. Therefore, when planning a semi-automatic or automatic A.T.C. data processing system, operational requirements should first be defined in detail. Then the programming capabilities of the planned computer and the equipment functions should be thoroughly analysed and evaluated in order to make those all important programme/equipment trade-off decisions.

One of the most important conclusions reached early, and later corroborated many times, is that air traffic control specialists trained as computer programmer supervisors are essential to obtain maximum A.T.C. system operational efficiency and optimum usage of the employed computer equipments. It is necessary that most of the people programming the equipment know both the Air Traffic Control System and the computer equipment intimately.

We have found it to be preferable, and quicker, to teach air traffic controllers programming than to teach programmers air traffic control. The time period required for a skilled A.T.C. specialist to become a productive programmer is usually from six months to a year, after attending a formal programming course for a particular computer.

Now let us move on to the output equipment area. The Phase 1 system originally used a bank of six inquiry typewriters with each computer to print flight progress strips in two colours and sizes of type. Incidentally, the controllers really like these machine-made strips. They are neat, legible and are notably more accurate than the original ones prepared manually by the assistant controllers—especially in time estimates and routings. However, because of computer limitations, it became necessary to replace each bank of typewriters with a modified high speed line printer capable of 500 lines a minute, which provides about a five to one speed improvement besides releasing five input/output tracks for other uses.

Centralised printing with a high speed line printer offers the advantage of keeping the noise of printing out of the operations room, but it does create a need for an automatic strip loader and an unwieldy transport system to deliver the strip holders automatically to the different control sectors.

In the D.P.C. system we are utilising a decentralised configuration of output strip printers at each sector that eliminates the problem of transporting the strips in their holders to the appropriate sectors. One disadvantage of this arrangement is that it uses valuable control room space.

We have developed the ability to supply either centralised or decentralised strip printing capability and will select the appropriate version for the particular environment.

The D.P.C., as mentioned earlier, uses the printed flight strip as a display device. We expect that the next generation of flight plan displays will be electronically generated and thus eliminate the need for bulky printing and flight strips updating electro-mechanical machinery. But, electronic displays of the future must have the non-destructive characteristics of the flight strip before acceptance will be forthcoming from the operational controller.

Our operational people have now agreed that our electronic controller displays should be bright enough to be useable in normal ambient daylight. At the moment we are generally working with two categories, the scan-converted TV raster cathode ray tube, and the character forming "Charactron" and "Typotron" tubes. We plan on using computer generated flight plan data to place appropriate alpha/numeric information on the face of the tube with the proper radar target. This information will be selectable by the controller and probably consist of flight identification, altitude, destination, etc.

The positioning of this pertinent control data will involve tracking gates and a requirement for aircraft position in terms of range, azimuth, and height (possibly 3–D radar information or radar beacon data) to maintain accurately the position of said data in proper relation to the moving targets. Generating moving flight plan data simultaneously on numerous control displays in this manner requires a tremendous amount of computer capacity. The data must be collected from internal storage, continually updated, and generated at a flicker free rate in consonance with the radar rpm. This is no small task and obviously requires the more sophisticated class of computer developed in the D.P.C. programmes.

To obtain these characteristics we have developed a solid state computer having 16,000 words of core memory and many times as much from numerous file drums and magnetic tape units as addressable storage. The average access time to this core is 6 micro seconds. This class of computer permits optimisation of the executive and functional programme routines, plus being capable of

efficiently handling the data processing loads during peak periods with some room for future expansion. In summary, when operating as a total system, the present design is intended to accept:

400 flight plans per hour by teletype.
Breakdown and store 440 flight plans per hour.
Store 1,000 pending flight plans.
Print 1,600 flight progress strips per hour.
Process 6,000 updatings per hour for 1,600 strips based on 2,600 keyboard entries per hour.
Transmit to SAGE all of the applicable flight plans and updates; and
Transmit to adjacent A.R.T.C.C.'s 220 flight plans and 1,300 updates per hour.

Legal recording is another similar subject. Operationally it is mandatory but we have not made a final decision on the exact place or places in the system that we wish to use for the legal source of data.

In conclusion the following are some of our most recent plans for using digital computation in the A.T.C. system. About nine months ago we embarked upon a combined implementation and development programme that should give us a noteworthy field improvement by the end of 1962. We are at present putting together a system that consists of the production versions of our new solid state Librascope computer group with many of the Phase 1 type peripheral equipments, and the addition of a new automatic electro-mechanical updating control console now under development. It is called the "Phase 1–1/2" system, since it is in between our Phase 1 and D.P.C. (Phase II) type systems, and is scheduled for testing in the latter part of 1962. This will be the first time that computer updating and automatic flight progress strip revisions will be available operationally. These updates will be entered by the controller on one of the special keyboards mentioned previously. The computer will digest this input and cause all the appropriate strips in the different flight data sector consoles to be moved laterally under a vertical print belt and automatically updated. A special adjunct necessary to this function is a printer and loader situated next to the sector that prints the flight progress strips and loads them into special holders. These strip holders are individually coded. The next function of the printer-loader is to note the aircraft identification, the fix designation, and the discrete holder code, and then relay this combined information back to the computer. Thus the computer will have the address and location in storage of any particular flight progress strip as it is required for updating purposes. The prototype of the entire system will be delivered to the F.A.A. Center later this year for checkout and evaluation; this will give an opportunity for "debugging" the equipment and making any minor changes required before installing in an operational centre.

The system will be completely compatible with the existing Phase 1 network as well as the D.P.C. systems. The advantages it will offer are first, the increased computer capacity will handle the present Phase 1 functions plus adding a fully automatic updating capability which is the number two function of the nine planned in our D.P.C. building block programme. The update function is a big step forward. Without it system outputs—especially displays—could not be kept current, which would negate most of the proposed computer derived improvements for the A.T.C. system. Next, the additional computer capacity will allow for sustained high peak loads with enough extra capability to add conflict detection and flow control at a later date without replacing the central computer group. We are very enthusiastic about the possibilities of this.

The results of Project TRAILSMOKE indicated that it is feasible to conduct radar advisory service from SAGE Direction Centers and to provide this service to all aircraft operating above level 240. In making this conclusion, the Bureau of Research and Development conducted special tests to determine the quality of the radar information as processed by the SAGE equipments, and the data was found to be comparable in quality to the raw video normally used at manual sites or in airway traffic control centres.

The work under Project SATIN has reached the point where design, which is essentially computer programme design, is virtually complete. Tests and evaluation activities are just now getting under way and will be aimed at determining the effectiveness of the SATIN techniques in the control of the *en-route* air traffic. F.A.A. controllers will take an active part in this evaluation and are now being trained to operate the SATIN consoles. Both simulated and live testing techniques will be employed, using inputs from the SATIN radar network as well as from the New York and Boston airway traffic control centres. A significant portion of this evaluation will be conducted between now and October 1961. In fact, a preliminary determination of the validity of the SATIN techniques of data processing and display is expected by that time.

In addition to our experience in the field with the Phase 1 programme and our development and experimentation up to the present time, we are also analysing technically and economically the use of computers for air traffic control. Some early conclusions from these studies are as follows:

Air Traffic is not steady even in the busiest areas. It comes and goes in surges. Since the systems must be designed to handle the peak surges, this means that A.T.C. computers must be over-designed in capacity and speed as high as 2 to 1. This extra capacity and calculating time can be used for administrative functions such as payroll formulation, self checking, statistical analysis of operations and even fast-time simulation for research purposes. Also, the standby computer can be used for research and development purposes, to run problems and report results back to the research and development centre.

In our analysis of weather forecasting computation needs for data processing and display, it appears that digital computation is required in amounts and geographical location suitable for inclusion as functions of the A.T.C. data processing computers. If this is proved, it will mean a substantial cost saving in the implementation of weather forecasting computers. Finally, the entire subject of aviation facilities in the U.S.A. is now

being studied by a special scientific group appointed by Mr. Halaby, the new Administrator of the F.A.A. The Bureau of Research and Development is assisting this group, headed by Mr. Richard Hough, in a three month scientific review of the current air traffic control system, and will recommend action to the Administrator to assure that the hard needs of aviation are met. We expect this review to be complete by the middle of 1961, and surely give new impetus to the utilisation of digital data processing for air traffic control.

Secondary Surveillance Radar and Airborne Transponder System

BY

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(Technical Director, Cossor Radar and Electronics Ltd.)

1. Introduction

The use of primary pulsed radar as a surveillance instrument in Air Traffic Control is familiar to most, and is a direct development of the various ground radars current in the last war. The wavelengths generally employed are 10 cms. for more local control, and 50 cms. for long range and high coverage. The primary radar depends for its information on reflection from the target aircraft of sequences of pulses of electromagnetic energy radiated by the aerial, and displays this information as a "paint" on a P.P.I. (Plan-Position Indicator) cathode ray tube giving range and bearing relative to the radar site. The radar beam is fan-shaped, narrow in the horizontal plane to a few degrees, and wide in the vertical plane to provide adequate vertical cover. The beam is made to scan through the target by a rotation of the aerial about a vertical axis up to a rate of 14 r.p.m. The beam width in the horizontal plane is necessarily kept narrow to provide adequate discrimination between targets at the same range but different bearings. The primary radar is frequently associated with a height-finding radar in which the beam shape is reversed, having a narrow angular cross section in the vertical plane. In this case the aerial is made to nod up and down along an appropriate azimuth selected by the controller, and the height of an aircraft is displayed on a height-range cathode ray tube.

A serious limitation of primary radar is that of "clutter" on the P.P.I. resulting from reflection of the radiated energy from local and distant terrain masking legitimate aircraft echoes. Most primary radars in operation today, however, are designed with a Moving Target Indicator (M.T.I.) facility. This facility enables echoes from fixed objects, such as hills, to be suppressed, but admits signals from moving aircraft having a radial velocity component relative to the radar site, and these can be seen on the P.P.I.

A further limitation of primary radar is that the signal received from the aircraft is a reflected signal, and as such, its magnitude is dependent on the size of the aircraft. Thus, although large transport aircraft are readily seen, light aircraft in the vicinity might be missed, with subsequent collision risk under I.F.R. conditions. Moreover, the information provided by the reflected signal is restricted, and cannot give information concerning identity, and so on, which clearly would be of great advantage to the Controller.

2. The Role of Secondary Radar in an A.T.C. System

Secondary radar originated in the Military I.F.F. (Identification, Friend or Foe) of the last war. In its earliest form, the system included an airborne beacon or transponder which was triggered by the primary radar; the nature of the signal then revealed whether the target was friendly or enemy. With the development of new radar equipment it became necessary to adopt a standard frequency for the beacon, and associated with a primary radar is therefore a ground interrogator equipment.

The potentialities of secondary radar as a facility for A.T.C. purposes were soon recognised after the war. Its advantages are:

(*a*) The response signal is dependent only on the beacon power, and hence light aircraft are seen as readily as large transport aircraft.

(*b*) The beacon is arranged to respond on a frequency slightly removed from the interrogator frequency, and is therefore seen free of ground clutter from the interrogator energy.

(*c*) The beacon response can be suitably coded to provide identity, height, air speed—or indeed many other parameters of an aircraft of advantage to a Controller.

Such a system was successfully demonstrated by the Royal Radar Establishment (then T.R.E.) to the first C.E.R.C.A. in 1945, and to the P.I.C.A.O. in 1946. The beacon was interrogated by the ground radar on S-band (10 cm.), and replied in the 200 Mc/s. band. The receiving array was a series of unipoles mounted on the rotating S-band reflector. A serious limitation of the system resulted from masking of the tiny S-band unipole on the aircraft in bank and turn. Since then, a more suitable frequency has been agreed upon internationally in the L-band region. The Interrogator interrogates on a frequency of 1,030 Mc/s., and the Transponder replies on a frequency of 1,090 Mc/s. Thus, the operation of the secondary system is entirely independent of primary radar frequencies.

3. The Combination of Primary and Secondary Radar

At no time has it ever been suggested that a secondary radar system should supplant, or even be used independently of, a primary radar. Its function at all times is to supplement the primary radar with a response free of clutter, and thus it provides a mutual cross check of position and bearing. Moreover, the coding facility of the transponder establishes a direct data link with the selected aircraft under control. Since therefore the interrogator response and the primary radar response are to be closely associated in the A.T.C. system, it is essential that the interrogator beam and the primary radar beam are closely aligned—in fact, to better than 1°—during scan if exact correlation is to be preserved.

Two schools of thought exist on the systems engineering of the secondary radar.

(*i*) The interrogator array should be mounted on the primary radar aerial structure. It is then argued that alignment of the two beams is an automatic geometrical function, and moreover a single aerial turning gear fulfils both the primary aerial scan function and the interrogator aerial scan function.

This system has, however, several serious disadvantages. In the first place the interrogator array must be a fairly substantial structure to resist flexure and consequent beam distortion in operation. The array, to be described later, has a horizontal aperture of 30 ft., and weighs approximately 700 lb. The attachment of such an array to an existing primary aerial imposes severe structural problems, and in particular might distort the main radar reflector and affect the integrity of the beam pattern of the main radar.

Moreover, the interrogator transmitter/receiver is preferably a static installation, and the design of a suitable co-axial rotating feed for both the primary radar and the secondary radar aerials presents an extremely difficult technical problem.

From a practical standpoint, both problems are acute when we wish to adapt secondary radar to existing primary radar systems.

(*ii*) The interrogator aerial array should be a separate entity, with its own mounting and turning gear. The turning gear is servo-controlled by a synchro link between the primary radar scanner and the interrogator array, and angular alignment can be maintained during rotation to better than 1°.

This, to my mind, is a more flexible and preferable system. Cost-wise, it is unlikely to be more expensive by the time a suitable co-axial feed is provided and the primary aerial mount sufficiently stiffened. Flexibility results from the fact that an interrogator aerial can be coupled to any primary radar on an airfield by the simple act of switching by the controller. The necessary co-ordinate adjustment can clearly be automatic.

Such a system is the one developed in this country which is now being evaluated by the Ministry of Aviation authorities at London Airport and which will be described later.

4. Side Lode Suppression

As is well known in the theory of aerial arrays and reflectors, the beam pattern of the radiated electromagnetic energy consists primarily of a main beam whose width is inversely related to the aperture of the array or reflector; but associated with the main beam are a number of contiguous minor beams or side lobes, and it is the design aim of an aerial to reduce the side lobes to a minimum. With a primary aerial, the side lobes are kept down to better than 20 dB. below the main beam. The effect of side lobes in any scanning array is effectively to broaden the beam, since as the pattern sweeps through the target each side lobe also makes its contribution to the received echo, and thus widens the arc of vision of the array. This clearly reduces the angular discrimination between targets at the same range.

For a primary radar, the effect of side lobes kept below 20 dB. is not too serious, since the power transmitted by a particular side lobe is reduced as well as the signal it receives after reflection. For secondary radar, however, this is not so, and the principle of a two-way reduction does not apply. Thus, if a side lobe has sufficient marginal power to trigger an airborne transponder, it will reply with the full transponder power. Experience has shown that with the most carefully designed aerial, side lobes in secondary radar have a most serious effect on discrimination between targets, and instead of a response over a 2° arc of scan, signals can occur over a 20°–30° arc of scan. Clearly this state of affairs is of limited assistance to a controller.

For this reason, therefore, in the design of a secondary radar system, considerable attention is paid to the elimination of triggering of an airborne transponder by the side lobes of the ground interrogator aerial array. The process is known technically as Side Lobe Suppression, or S.L.S.

A great deal of technical controversy has ensued over the past two to three years between the American and British authorities over the type of side lobe supression to be employed and standardised internationally. To this controversy must be added the military dilemma with its I.F.F. equipment, which must eventually clearly conform to an A.T.C. pattern. Present Services I.F.F. equipments—existing in large quantities—are not side lobe suppressed, and any modification must clearly cause them concern.

The American authorities have tended to favour a three-pulse Side Lobe Suppression system, whereas the British authorities, acting on early I.C.A.O. recommendations, had already embarked on a two-pulse Side Lobe Suppression programme. The situation has been resolved to a great extent by a recent agreement between the two Governments which enables a compatible system to be employed. It was recognised that the U.K., for the present would employ a two-pulse S.L.S. ground equipment, and that the Americans might well concentrate

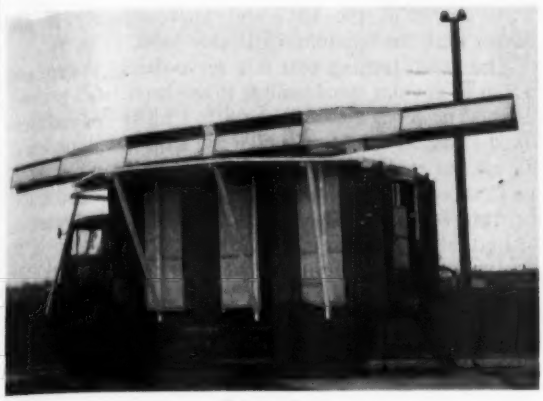


FIGURE 1.

on a three-pulse S.L.S. system. It would then be necessary for all airborne transponders to be capable of replying to either form of interrogation, and future transponders would be designed and modified for this compatibility.

The SSR.4G Ground Interrogator equipment designed and installed at London Airport by Cossor Radar & Electronics Ltd. for the Ministry of Aviation is a two-pulse S.L.S. system, and the Cossor SSR.1251 Airborne Transponder now being currently used by B.O.A.C. in their Boeing 707 flights, and being fitted by Air France and Air India, is also a two-pulse unit.

The issue hitherto has not been critical; for although it is mandatory that all civil aircraft operating at heights above 25,000 ft. across the U.S.A. from New York to San Francisco shall carry a transponder, so far the Americans are employing non-side lobe suppressed equipment, which therefore triggers either type of transponder, be it a two-pulse or three-pulse system. It must be realised, of course, that such interrogators have all the inherent shortcomings mentioned earlier, and the system can only have limited operational advantages to the controllers.

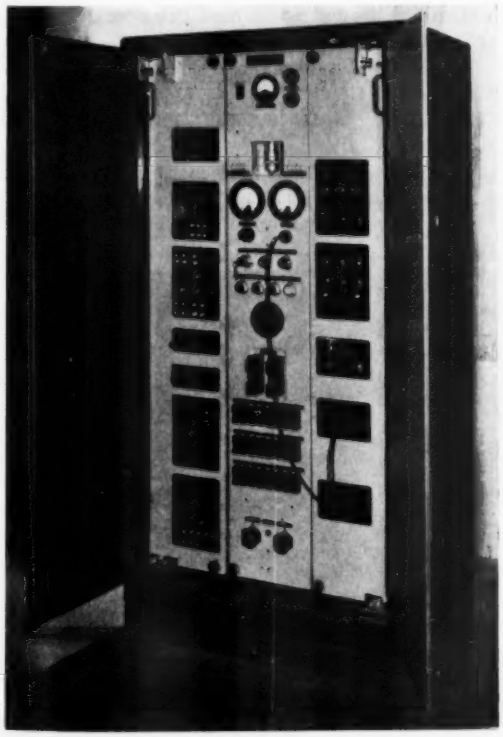


FIGURE 2.

Meanwhile, a modification has been designed for the SSR.1251 enabling it to be compatible with either two- or three-pulse interrogation. If and when the necessity arises, all current units can readily be retrospectively modified. In these circumstances, therefore, and irrespective of which system is to be finally adopted internationally, a secondary radar system is now working and can remain an operational system. It is, however, gratifying, and perhaps a matter of national pride, to note that whereas, to the best of my knowledge, our American friends do not have a three-pulse interrogator in operation, the British authorities do at least have in existence a side lobe suppressed interrogator, albeit that it is a two-pulse system. I might add that the design of the present SSR.4G is sufficiently flexible to admit conversion to a three-pulse system fairly readily, but it is the policy of the Ministry of Aviation, and one which we whole-heartedly support, that evaluation trials should be conducted on the present system without chop and change.

5. The SSR.4G Ground Interrogator Equipment

I will now deal with a description of the equipments which form fundamental bricks in the secondary radar A.T.C. philosophy. I regret that in the time at my disposal I cannot deal with this in the detail I should have liked. Equally I regret not having time to describe the three-pulse alternative.

The first equipment is the SSR.4G (Fig. 1). The equipment has in the first instance been mounted in a trailer for obvious reasons, but it can equally be provided as a static installation on any airfield.

The equipment is designed for two-pulse operation as a side lobe suppressed system. The two-pulse S.L.S. system requires the transmission of a pair of R.F. pulses $0{\cdot}85\mu$Secs. wide. The first pulse of a pair is called the control pulse, and the second the interrogator pulse. The interval between the pair depends on the mode chosen, and it can operate on two modes—Mode *A* with a separation of 8μSecs., or Mode *B*, with a separation of 17μSecs. Mode *A* is reserved for military interrogation of I.F.F. transponders, and Mode *B* for civil interroggation. Both pulses occur in the pulse repetition period, which is timed from a trigger pulse derived from the primary radar over a land-line, and hence locked in synchronism to the primary radar. In the present equipment, Modes *A* and *B* are transmitted sequentially, that is, interlaced in successive pulse recurrence periods.

The aerial system consists of two parts, the interrogator array having an effective interrogation beam width of $2{\cdot}5°$, and a combined control aerial. The interrogator

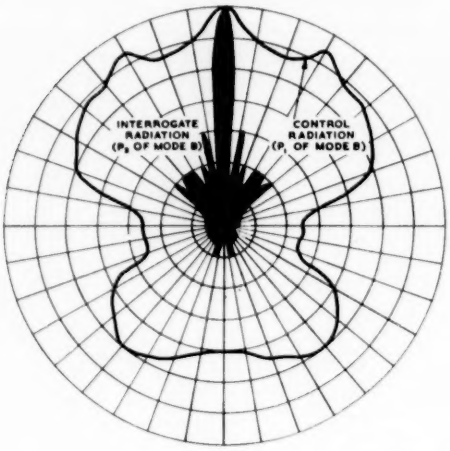


FIGURE 3.

array consists of 48 unipole elements divided into six sections, with reflector of eight elements each. The 48 elements are centre-fed from a binary system of feeders, the amplitude being suitably tapered to adjust illumination over the aperture for minimum side lobes. In fact, the maximum side lobes occur at $\pm 10°$ with respect to the centre of the main lobe and reduced in power by approximately 20 dB. on the main lobe. The aperture in the vertical plane is narrow, giving something like a 45° beam width between $\frac{1}{2}$ power points, in a free space pattern.

The control portion of the array consists of two single unipole-fed central sections, one in front and one to the rear of the array. The radiated control power is then distributed approximately omnidirectionally through 360°. Part of the control power is also fed to sections of the interrogator array to provide a greater field strength along the main interrogator beam. The interrogator aerial serves as a common array for transmission of power on 1030 ± 15 Mc/s. and reception of the airborne transponder reply on 1090 ± 15 Mc/s. Its bandwidth must therefore cover 1015–1105 Mc/s.

To ensure frequency stability and freedom from frequency pulling effects by the aerial, the transmitter power is generated from a crystal operating on 38 Mc/s. at C.W. This signal is then progressively tripled to 114·1 Mc/s., to 343·3 Mc/s., and finally to 1030 Mc/s. Some of these stages are pulsed in their amplifiers and are further amplified in a common amplifier. Two pulses of R.F. power are generated in this process, the first being the control pulse (C.P.) at 10 kW peak power and fed into the control section of the array, and the second the interrogator pulse (I.P.) at 1 kW peak power fed into the interrogator array. The power switching is accomplished electronically with the necessary mode separation interval within a pulse recurrence period. The aerial gains and powers are so designed and adjusted that along the centre of the main interrogator beam the field strength of both C.P. and I.P. are equal. At angles beyond the main beam, the field strength of the two pulses are such that the C.P. is 10 dB. below the main beam power of the I.P., and approximately 10 dB. greater than the maximum I.P. side lobe. (Fig. 3).

The aerial turning gear is a servo-driven system and locked in angular synchronism to the associated primary radar. The servo system chosen is a fairly conventional Ward-Leonard system in which the amplifiers operate at 400 c/s. for reasons of quicker response. A 50 c/s. three-phase motor drives a 400 c/s. alternator and also a d.c. generator. The field excitation of the generator is derived from the misalignment error signal between 50 c/s. synchros on the primary radar turning shaft and the SSR.4G turning shaft. The output current of the d.c. generator is then fed to a d.c. turning motor capable of a peak power output of 12 h.p. Trials indicate that synchronism can be maintained to better than 1°, although gust conditions must be investigated.

The received signal from a transponder is separated through a duplexer and a 45 Mc/s I.F. channel, and finally emerges as a video signal of maximum amplitude of 5 volts from a 50 ohm source impedance. It can then be routed to any number of P.P.I. displays or into a decoder computer.

6. The SSR.1251 Airborne Transponder (Fig. 4)

The complete airborne installation consists of the Transponder, the SSR.1251; a pilot's control unit, SSR.1252; and an L-Band aerial SSR.1253, mounted on the aircraft skin. These are designed in accordance with the recommendations of I.C.A.O. and the ARINC Characteristic 532B. The equipment is suitable for unpressurised operation up to 20,000 ft., and when used with standard ground equipment the operational range exceeds 180 n.m.

The transponder circuits are housed in a $\frac{1}{2}$ ATR long case for standard ATR rack mounting, and operates on the 400 c/s. aircraft supplies. It consists essentially of:

(1) An L-band transmitter capable of producing a peak power of 500 watts ± 3 dB. on 1090 Mc/s. (average production units give about 400 watts);

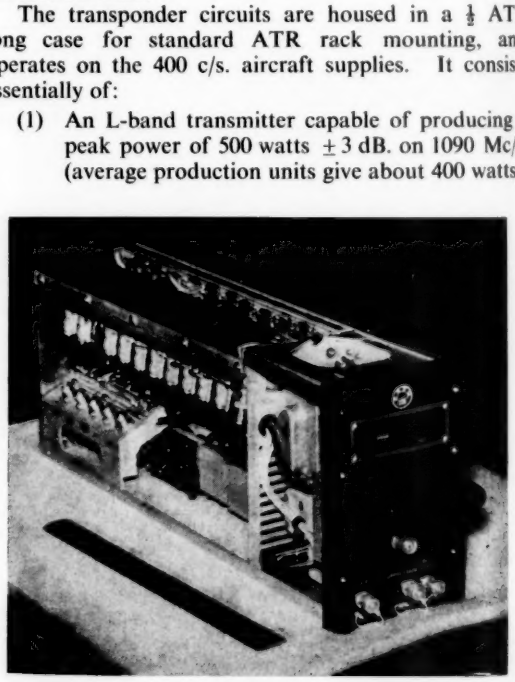
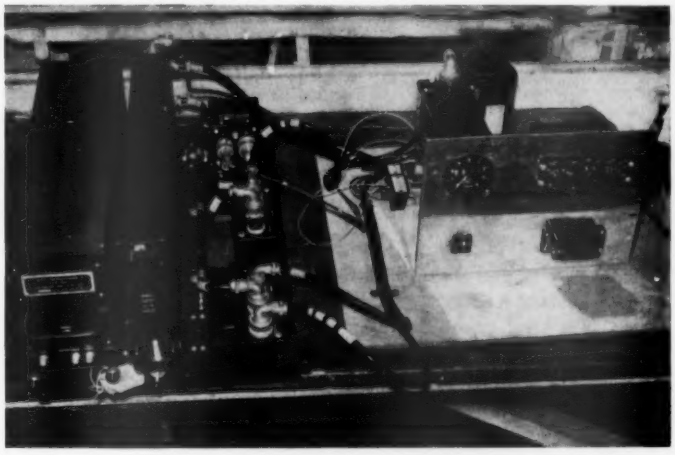


FIGURE 4.

FIGURE 5.



(2) A duplexer which receives pulses at 1030 Mc/s. from the ground interrogator;
(3) An I.F. (intermediate frequency) amplifier at 60 Mc/s.;
(4) Delay network and discrimination unit;
(5) Encoding unit;
(6) Power modulator.

The mode can be selected on the pilot's control unit. The sequence of operation is as follows. The control pulse is received from the ground, and fed into a storage magneto-striction delay line over the mode interval until the second or interrogator pulse arrives from the ground. If these two pulses are of different magnitudes, as occurs at angles of the main beam, the trigger circuits remain quiescent. If, on the other hand, these two pulses are equal, within narrow limits, as occurs when the main beam sweeps through the aircraft, the trigger circuits are fired, and they generate two framing pulses 0·45μSecs. wide separated by 20·3μSecs. In addition, and according to the code selected on the pilot's control unit, there are also generated up to a maximum of six similar pulses, equally spaced at 2·9μSecs. apart, by the encoder unit. These pulses are now made to act as the modulator pulses, and the transponder then replies with this sequence of pulses per pulse recurrent interval. The code is set by the selection or omission of any of the six coding pulses in a digital manner, and as such is capable of transmitting 64 separate codes. Increasing the encoding unit to supply 12 pulses raises this number to 64^2, or 4096, separate codes. The potentialities of the encoding system are therefore enormous.

The siting of the aerial on the aircraft is rather critical, and it must be visible to the ground beam without screening by the aircraft structure. We are currently engaged with B.O.A.C. in determining the optimum site on the Boeing 707, since a bad site leads to fades and sharp cut-offs, and consequent poor range performance.

7. Future Possibilities and Conclusion

It is clear that the secondary radar system described admits of a number of possible operational roles:

(*a*) The transponder signal can be displayed on any number of P.P.I.'s sited at any control centre. These signals are free from clutter and independent of aircraft size, and can be consistent with and confirmatory to an associated primary radar display.

(*b*) The transponder reply can be suitably encoded according to a pre-arranged drill by the pilot. The code possibilities are clearly large in number, and can be designed to be most informative to a control centre.

It must be pointed out that developments in the latter field are rather exploratory at the moment. Further development is necessary to provide:

(*i*) A suitable "de-fruiting" apparatus which will suppress unlocked responses from any transponder being simultaneously triggered by another ground equipment.

(*ii*) A suitable decoder equipment; at the best the framing pulses and code pulses are far too compressed on a P.P.I., and in general would be unintelligible to a controller watching them. On the other hand, an automatic decoder can be designed, either of the passive or the active type. The former admits and displays only a pre-arranged code, whereas the latter scans and decodes any code sent by the aircraft.

All these aspects are receiving a fair amount of thought at present, and it is hoped that the requirements will become firm in the near future.

An interesting experimental trial is now being made in conjunction with Cossors by the Ministry of Aviation on height encoding. (*See* Fig. 5). A Smith's Servo 100,000 ft. altimeter is used in an aircraft to provide coded heights at 500 ft. intervals in digital form up to 64 codes, that is to 32,000 ft. These successive automatic height codes are then applied to the transponder, which signals to the ground station when interrogated. Decoding of the reply will then provide, in addition to range and bearing, the aircraft height to the specified limits of accuracy. Clearly, by increasing the number of codes provided by the transponder, other information can be transmitted simultaneously, such as identity, and so on.

I hope that my paper will serve as a basis to stimulate operational ideas on the future exploitation of secondary radar systems in the role of A.T.C.

The Future of Air Traffic Control

BY

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(Director, Aviation Control and Navigation Development and Planning, Ministry of Aviation)

THE purpose of this contribution is to draw attention to some of the major areas in A.T.C. where there are difficulties and to outline the steps that are being taken to surmount them.

Before looking quickly at some of the technical problems I think it might be worth taking a brief look at two important aspects which surmount the whole scene: namely the Civil/Military situation and the birth of Eurocontrol.

The relationship between service and civil authorities on A.T.C. matters springs directly from the differing requirements of the two sides for air space. The increasing use of jets by civil operators has made this problem more acute because now the Service aircraft not only have to be shepherded up through the commercial traffic, but also protected from them in the upper levels. The requirements of research aircraft are also stringent and yet again, different.

Under the auspices of the A.T.C. Board it has been possible to work out a common policy and to develop agreed procedures and standards of efficiency, the aim being to provide a joint A.T.C. service manned as appropriate by civilian and military personnel. There is much to be said for having both categories of personnel involved—there can then never be any accusation of 'Why don't "they" do something for "us" instead of just looking after "their own"?' However, there is little doubt that there is room for further development in the area and I have no doubt that the Board's Working Party, under Air Chief Marshal Sir Hubert Patch, have given this much thought.

On the practical side of this problem, you will no doubt have read the extracts from this year's Air Estimates on the subject of radar. Here we have a most significant development because it has clearly been stated that the high-powered radar and associated radar data handling equipment now on order for defence purposes will be used also for A.T.C. and that, in addition, the main Defence Control Centre will be located close to an Air Traffic Control Centre, so as to ensure that the most value can be gained from this equipment. These are not just simple, pious hopes for the long term future and I can assure you that much detailed planning has been and is going on so as to weld the defence radar system to the A.T.C. organisation, not just to the civil A.T.C. but to the joint civil/military A.T.C. service. In all cases I can say that it is intended that, to ensure that nothing is missed, there shall be raw radar information at Air Traffic Control Centres as well as processed, tabulated and computed information.

The second major planning development of the past two years is the birth of Eurocontrol. An interim "Planning Directorate" is now being set up. Its Director and his three principal deputies have already taken up their posts and probably within a year the definitive organisation will be in existence. The aim of Eurocontrol is to develop and provide an Air Traffic Control service above 20,000 ft. over the air space of the member States (Belgium, France, Germany, Luxembourg, the Netherlands and the U.K.). Later there may be other adherents to the Convention.

Quite how this control service will be formed is not yet known but one thing is certain: the number of Flight Information Regions will be drastically curtailed, probably to four—two on the mainland, one covering most of the U.K. and the other in the U.K. forming a bridge to the Atlantic. An area type of control is envisaged but it is not expected that this will emerge in its purest form at the outset. A more likely evolutionary move will be the introduction of planned "predetermined" routes within an area so as to provide some basic network on which to develop the Centres.

In the U.K. at any rate it is expected that the Eurocontrol Centres will be grafted on to the existing low level A.T.C.C.s; in fact it is likely that by the time Eurocontrol is ready to take over the upper air space control there will be in existence quite an effective joint system already in operation which will have been evolved in the closest association with the Eurocontrol Planning Directorate.

Main Domestic A.T.C. Plan until 1965-69

The first requirement is to decide the geometry of controlled air space. The main changes planned include parallel tracks within existing width airways; discrete climb and descent paths to and from the upper air space without prejudice to aircraft in the lower levels; upper air routes above 25,000 ft.; high level holding areas in the vicinity of terminal areas.

Air Traffic Control Centres

The largest single air traffic control planning task is the design for the Air Traffic Control Centre of the future and how best to collect, store, sort and display information. It is important here to avoid the trap of attempting to automate the old system because it appears that a little time might be saved.

The United Kingdom plan divides the Centre into four main units:

(*i*) *A Flight Plan Processing Section* which will receive and manipulate the basic flight plan from the operator.

(*ii*) *A Movement Planning Section* where various requests for flight clearances will be sorted into a comprehensive plan and initial clearances given.

FIGURE 1. An architect's drawing of the new S.A.T.C.C.

(*iii*) *A Flight Control Section* where controllers will have a radar picture of the sector before them and will speak to and control the aircraft.

(*iv*) *The Radar Filter Section* will be the unit which selects, identifies and follows the responses of the aircraft passing along the routes, thus providing the Flight Controller with his working data.

Data Processing in A.T.C.

A.T.C.C.s throughout the world are experimenting with automation. No very great successes have yet been achieved, but some of the lessons learned will be invaluable for the future.

Basically, data processing falls into two categories, procedural and radar. While treatment of them can proceed independently, it is essential that their outputs should be complementary because the resultant information from each source needs to be used to improve the data of the other.

Procedural Data Processing

The Movement Planning Section itself offers great scope in this field, both internally and between Centre and aerodromes. With this in mind the first step will be to introduce a system for processing and printing flight plans within the Centre. I hope that our deliberate late start with hardware will ensure that we have an equipment which will play a real part in the Air Traffic Control Centres of 1964.

The system will have to be highly reliable and, in the event of failure, it must be possible to revert to manual operation without delay and without loss of information already stored in the mechanised system. Figure 2 shows sample strips, written by hand, printed on a teleprinter, and two examples of the improved type.

I will come back to procedural data processing later.

Radar

Radar has already established itself as one of the most important, if not the most important, single tool of the air traffic controller. There are some who think that since we are dealing with a co-operative population, the days of radar for *en route* work are numbered. While I am in favour of better navigation and the use of data links, I do not believe that we can, or should, dispense with primary radar where it can be obtained.

There are some interesting possibilities ahead: for example, 3D equipment. By using height banding it may be simpler to apply automatic tracking in the less dense upper air space or, in reverse, to clean up a low level picture. I doubt whether 3D radar will replace the need for telemetering altimeter readings from the aircraft to the ground.

Secondary radar will be a great boon to the controller to aid identification and, I hope, provide height.

Much has already been done by the electronics industry towards the provision of clean pictures and interscan displays and the conversion into digital form

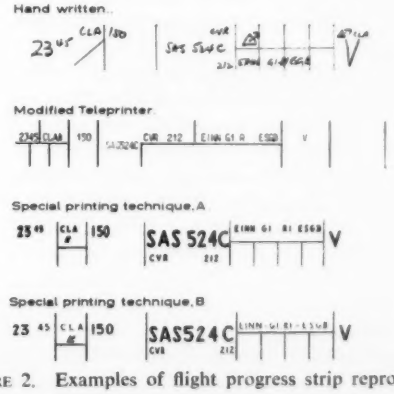

FIGURE 2. Examples of flight progress strip reproduction.

of radar information so that it can be processed by computers. Some say the task of the A.T.C. planner is simply to decide what he wants and, hey presto, the radio industry will provide! That may be partly true, but the major use of the processed radar picture has still to be worked out with our military colleagues.

Terminal Area Control Problems

I do not propose to spend very long on the Terminal Area problem today, except to say that it is one of the most difficult to handle, since each area has so many personal idiosyncrasies which make general solutions inapplicable. Adequate air space to manoeuvre is essential. In addition, aircraft must be able to navigate accurately. You have heard certain of our plans for installing VORs but the British view on the requirements for short range navigation aids is well known. I do not think the matter will rest here permanently because I believe the advantages and flexibility of an area coverage system will eventually become apparent to all. As far as possible discrete inbound and outbound routeings should be sought with the minimum number of crossings. Stacks, or rallying points, with access to the aerodrome clear of outbound routes are essential, preferably about 7-10 minutes flying time from the runways. If runways are to be kept fully used in peak periods, the operators must accept some delay, probably of the order of five to ten minutes for all aircraft. Some authorities seem cleverer than others in concealing these delays, but they are there just the same! A considerable amount of work is being done towards sorting out the traffic patterns for Terminal Areas and in evolving new techniques and we are watching with great interest the study that has been commissioned by the F.A.A. in this area. We shall also be interested to see the practicability of their high definition, short range height finders.

North Atlantic

The North Atlantic, an area of some four million square miles, has by international agreement a simplified area control system for all aircraft above 2,000 ft. amsl. At present the flow of traffic at any one time is mostly in one direction and then reverses. Traffic is light when viewed only in relation to the large amount of available air space, but as aircraft tracks tend to converge into comparatively narrow bands and because of the large procedural separation standards which obtain in this area, traffic densities are frequently high.

The separation standards now in use were internationally agreed in 1954. The level of traffic since then has increased from 30,000 to 50,000 movements per year, but experience has not yet provided sufficient evidence to change them either way. They are beginning to result in congestion and this, if not checked, will lead to delays and uneconomic clearances and possibly, in a few cases, to unscheduled technical stops. Hence, separation standards must be reduced, but by how much?

The picture in the Prestwick/Shannon Oceanic Control Area is changing rapidly. In 1959 little more than 10 per cent of the scheduled passenger traffic was jet, which became nearly 50 per cent last year and may be 80 per cent this year and probably 90 per cent by 1965. In parallel the present 200 a day peak rate is expected to increase by 1965 to 300 a day. There is already more traffic on the West side of the Atlantic than the East. Soon there will be no air traffic control problem below 30,000 ft. However, above 30,000 ft. the problem will be severe, with aircraft concentrated in a narrow height band where the vertical separation standard is 2,000 ft.

All in all, I believe that we should aim now at reducing horizontal separation to 30 miles and longitudinal separation to 15 minutes. I doubt whether the vertical separation standard above 29,000 ft. can be safely reduced to 1,000 ft. These aims lead to the need for a navigation system with an accuracy of about five miles (standard deviation). In defining accuracy in this way it is also necessary to state that additionally blunders should rarely exceed 15 miles.

Communications on the North Atlantic need to be improved, both in continuity and in speed, so that the controller receives the necessary information in good time and all the time.

You have heard of our low level cross-channel problems. *Ad hoc* schemes are wearing a little thin. I believe that there is little doubt that before the problem has been solved there will have to be radar cover in the area, responders in the aircraft and good and accurate navigational aids. Computers may well be called into service. A detailed study of this ticklish problem has recently been started and this season's traffic will be watched and analysed with great care.

Supersonic Transport Aircraft

Even though the I.A.T.A. Conference on supersonic aircraft is in session now, a paper at this time would not be complete without some reference to supersonic transport aircraft.

The difference between the performance of subsonic and supersonic jet transports is sufficiently great to create an impression that a new system of air traffic control will be required. Is this valid? Before examining the subject let me say that I believe (since they will be in a very small minority) it will be essential for the supersonic aircraft to be designed with low speed characteristics not dissimilar from present subsonic jets. If this is not so, either the many will be penalised or special airports would be required for supersonic transports.

Take-off climb—An early turn after take-off will in many instances ensure an early climb. It would also help to maintain a high runway movement rate. A maximum speed limit of about 300 knots should permit a high rate small radius turn. Once clear the climb can proceed at a very high rate at about 500 knots, but in this brief phase new control techniques will be required, with a bonus on discrete tracks.

Transition to supersonic speed and the subsequent supersonic climb—A block of air space some 130 n.miles long will probably have to be reserved between 35,000 and 40,000 ft. for transition to supersonic speed. Collision prediction and avoidance between the supersonic aircraft and crossing high speed aircraft, based on simple radar control, will probably not be practicable.

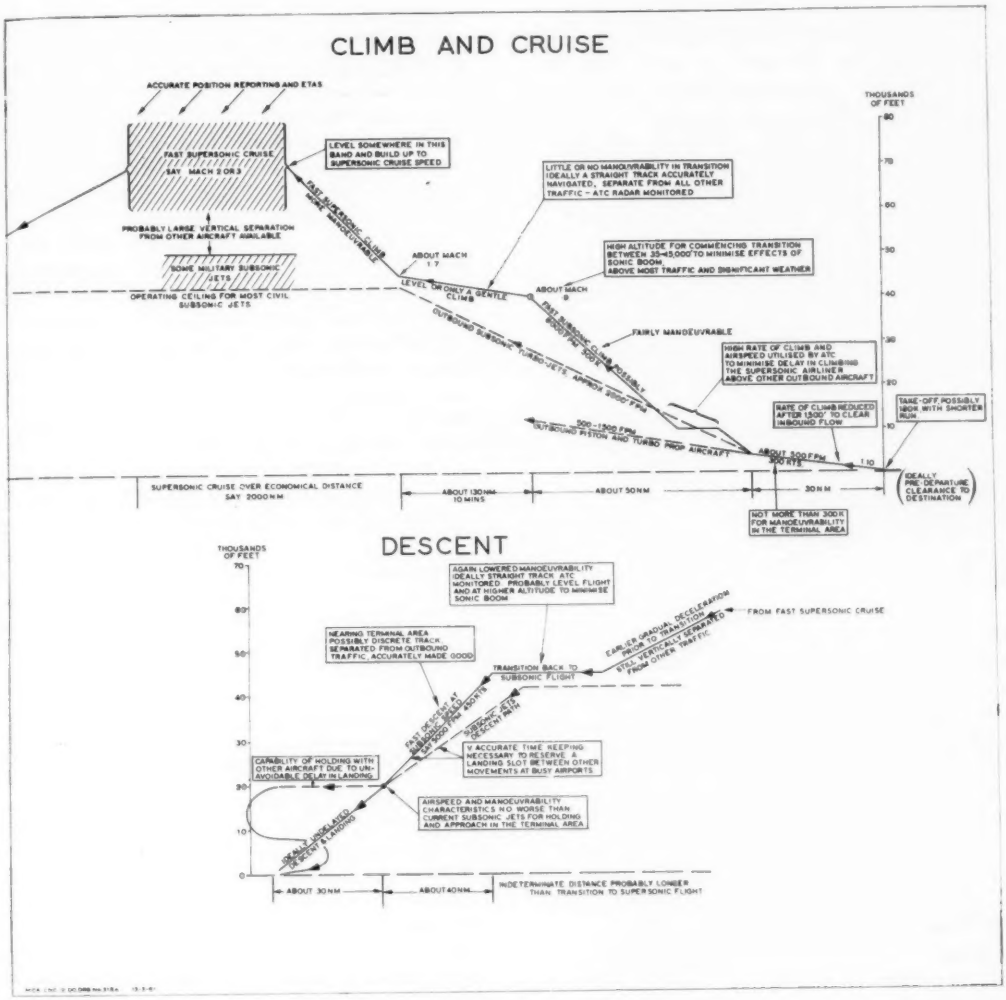
CLIMB AND CRUISE
ACCURATE POSITION REPORTING AND ETAS
FAST SUPERSONIC CRUISE SAY MACH 2 OR 3
PROBABLY LARGE VERTICAL SEPARATION FROM OTHER AIRCRAFT AVAILABLE
SOME MILITARY SUBSONIC JETS
OPERATING CEILING FOR MOST CIVIL SUBSONIC JETS
LEVEL SOMEWHERE IN THIS BAND AND BUILD UP TO SUPERSONIC CRUISE SPEED
FAST SUPERSONIC CLIMB
LITTLE OR NO MANOEUVRABILITY IN TRANSITION IDEALLY A STRAIGHT TRACK ACCURATELY NAVIGATED, SEPARATE FROM ALL OTHER TRAFFIC – ATC RADAR MONITORED
ABOUT MACH 1.7
HIGH ALTITUDE FOR COMMENCING TRANSITION BETWEEN 35–45,000 TO MINIMISE EFFECTS OF SONIC BOOM ABOVE MOST TRAFFIC AND SIGNIFICANT WEATHER
LEVEL OR ONLY A GENTLE CLIMB
ABOUT MACH 1
FAIRLY MANOEUVRABLE
OUTBOUND SUBSONIC TURBO-JETS, APPROX SPEED 475 KTS
HIGH RATE OF CLIMB AND AIRSPEED UTILISED BY ATC TO MINIMISE DELAY IN CLIMB AND THE SUPERSONIC AIRLINER ABOVE OTHER OUTBOUND AIRCRAFT
RATE OF CLIMB REDUCED AFTER 13,000' TO CLEAR INBOUND FLOW
TAKE-OFF POSSIBLY HIGH WITH SHORTER RUN
500 – 1,500 FPM OUTBOUND PISTON AND TURBO PROP AIRCRAFT
ABOUT 500 FPM 300 KTS
1.10
IDEALLY PRE-DEPARTURE CLEARANCE TO DESTINATION
SUPERSONIC CRUISE OVER ECONOMICAL DISTANCE SAY 2000 NM
ABOUT 130 NM 10 MINS
ABOUT 50 NM
30 NM
NOT MORE THAN 300 K FOR MANOEUVRABILITY IN THE TERMINAL AREA
THOUSANDS OF FEET
DESCENT
AGAIN LOWERED MANOEUVRABILITY IDEALLY STRAIGHT TRACK ATC MONITORED PROBABLY LEVEL FLIGHT AND AT HIGHER ALTITUDE TO MINIMISE SONIC BOOM
FROM FAST SUPERSONIC CRUISE
NEARING TERMINAL AREA POSSIBLY DISCRETE TRACK SEPARATED FROM OUTBOUND TRAFFIC, ACCURATELY MADE GOOD
CAREFULLY GRADUAL DECELERATION PRIOR TO TRANSITION
STILL VERTICALLY SEPARATED FROM OTHER TRAFFIC
TRANSITION BACK TO SUBSONIC FLIGHT
RATE OF DESCENT AT REDUCED MACH NO WITH SUBSONIC JETS
SUBSONIC JETS RATE OF DESCENT
V ACCURATE TIME KEEPING NECESSARY TO RESERVE A LANDING SLOT BETWEEN OTHER MOVEMENTS AT BUSY AIRPORTS
CAPABILITY OF HOLDING WITH OTHER AIRCRAFT DUE TO UNAVOIDABLE DELAY IN LANDING
AIRSPEED AND MANOEUVRABILITY CHARACTERISTICS NO WORSE THAN CURRENT SUBSONIC JETS FOR HOLDING AND APPROACH IN THE TERMINAL AREA
READY UNRELATED TO RECENT PLANNING
ABOUT 30 NM
ABOUT 40 NM
INDETERMINATE DISTANCE PROBABLY LONGER THAN TRANSITION TO SUPERSONIC FLIGHT

FIGURE 3. Supersonic aircraft; typical flight profiles.

In transit to supersonic speed the aircraft will probably not be able to contribute to avoiding action, except in dire emergency.

En route—Ideally, through clearance from departure to destination is required. However, while clearance for the whole *en route* segment may be possible I doubt whether it will be possible to guarantee an uninterrupted descent and a straight-in approach into a reasonable sized time "slot" between successive movements without serious loss of airport capacity.

The Approach to the Terminal Control Area—The transition from supersonic speed follows a similar pattern to that described earlier with the additional emphasis that the point and time at which the aircraft can begin to be regarded as a subsonic jet should be predictable fairly accurately. Provision for holding will be necessary but, I hope, used sparingly.

Navigational Aids—In subsonic flight there are no unique requirements. *En route* the self-contained navigational systems likely to be provided for close adherence to the flight plan may be expected to serve control needs, plus possibly a ground-based backup.

Problems of Automation in A.T.C.

The introduction of automation into A.T.C. simplifies some of the controller's work but it may well add complications. Here the study of man-machine relationship assumes great importance. The pencil is on the way out, the keyboard is approaching. The very keyboards themselves present a challenge and merit studies of their own. Will controllers be able to assimilate and react to the increased volume of data presented to them at the speeds achievable by automatic devices, or will completely new procedures have to be developed?

A truly automatic control system must be adept not only at detecting, but also at correcting errors. By its nature, an automatic system concentrates operations so that even if some distribution of work between the various units were organised, their number would still be small

and their failure could seriously impair the operation as a whole. Studies on reliability and efficiency of automatic equipment will therefore go hand in hand with the development of the fully automatic control system.

This leads to the need for an Air Traffic Control Experimental or Evaluation Unit. Work on equipment and techniques and long term theory is already being undertaken at the Royal Aircraft Establishment and the Royal Radar Establishment but this does not do away with the need for an establishment which concentrates on working up methods of applying these modern devices so that they can be developed into an A.T.C. system. All A.T.C. is neither electronic nor mechanical so that the final scheme evolves from a Unit where systems can be put to the test in a quasi-operational environment.

The Unit's main functions lie in the investigation of problems and the testing of solutions, with the emphasis on operational applicability rather than technical research and its tasks range from operational research studies, through the simulation of systems and equipment evaluations, to live field trials. Its work is directed towards evolving detailed requirements for the operational performance of new systems and equipments.

In the Ministry's programme for the application of automatic assistance to A.T.C., the A.T.C.E.U. (Air Traffic Control Experimental Unit) has played and will continue to play a leading part. It has already been working on radar processing and flight progress strip printing. In the near future it will be responsible for the conduct of the trials programme of the Ferranti Apollo Computer at Prestwick. This equipment will concentrate on the Atlantic problem and will also provide an excellent basis for the A.T.C. service to become computer-minded. In about two years time the recently commissioned Elliott computer and display system, being developed largely to requirements proposed by the Unit, will be installed at the new combined A.T.C.E.U./A.T.C. School building at Hurn. From experimental work on both the Apollo and Elliott equipments we should then be able to see more clearly the way in which automatic computing machinery and displays can be used to serve Air Traffic Control.

Why Air Traffic Control?

COULD AN AIR-TO-AIR COLLISION AVOIDANCE SYSTEM RADICALLY AFFECT THE TECHNIQUES OF AIR TRAFFIC CONTROL?

BY

R. F. HANSFORD

(Head of Display and Data Laboratory, Decca Radar Ltd.)

1. Introduction

To avoid any misunderstandings, it should be made clear that in the author's opinion the techniques of Air Traffic Control are *not* likely to be significantly affected by the future advent of an air-to-air collision avoidance system. This is admittedly a contentious view and this paper is a brief survey of some of the factors which lead the author to hold this opinion. After clarifying what is meant by an air-to-air collision avoidance system, the paper deals first with some of the operational problems, then with some of the technical problems and concludes with general comments.

2. Definition of Requirement

It is assumed for the purpose of this paper that a system of collision avoidance is envisaged which is wholly airborne. It is assumed that the system should give the pilot adequate warning of the presence of a risk of collision. It is further assumed that the system should help the pilot to decide on the correct manoeuvre which he should employ to escape the collision threat.

It is particularly important to distinguish clearly between a collision avoidance system as proposed above and a proximity warning indicator, which merely indicates that another aircraft is near, without indicating whether it presents a collision threat and without aiding the selection of the appropriate manoeuvre. It would seem that such a proximity warning indicator could have only very limited applicability, and in most cases would serve only to harrass the pilot.

3. Operational Problems

One of the major operational problems is to decide what period of warning is required of the presence of a collision risk. It is clear that this warning must be sufficiently long to allow either the pilot or a totally automatic system time to decide on the correct escape manoeuvre and to initiate and complete it in such a manner that a safe separation can be achieved without subjecting the aircraft and passengers to unacceptable accelerations. A time of the order of 30 seconds warning that a collision risk exists has often been proposed and it is interesting to note that this, for two aircraft approaching one another at 1,000 knots, implies that the risk has been assessed when the aircraft are separated by about eight miles. First detection of the presence of the aircraft is clearly required some distance in advance of this. This poses considerable technical problems.

Whether the avoiding action is to be taken by the pilot or completely automatically, it is essential that explicit

rules be formulated to define what avoiding action should be taken and that these rules should be applicable in any situation. Perhaps one of the most difficult problems in formulating the rules is to decide whether they should be based upon mutual avoiding action by both aircraft, or on unilateral action by one of them; unless rules can be devised to lay down an action which is safe in either case the problem clearly arises of knowing whether the other aircraft is also aware of the collision risk and whether he will or will not take avoiding action.

It is interesting in this connection to note that the majority of merchant shipping has for many years been fitted with excellent radar systems capable of warning of the presence of other vessels and that a number of advances have been made in recent years to aid the rapid determination of collision risk and the determination of the correct manoeuvring action. Despite this a number of collisions between radar-fitted vessels occur and it is often argued that at least one of the contributory causes is that the rule of the road at sea is based on the assumption that sighting is mutual. So far none of the authorities has been able to propose and agree on rules of the road that are fully applicable to radar-fitted vessels. Further, it is becoming clear in the marine case that one precept of manoeuvring on radar information, that of making alterations bold and early, is often impracticable in crowded waterways.

A major operational problem is whether an airborne collision avoidance system should be used in terminal areas as well as in the *en route* phase, or whether it can be used only in the latter case. Particularly if the system is used in crowded terminal areas it would seem that unexpected individual action on the part of aircraft would greatly complicate the task of any ground traffic control system. In such areas, also, an aircraft in manoeuvring to avoid a particular collision threat might well bring another aircraft into hazard, and it would seem that selection of the correct escape manoeuvre could only be made after assessing the action of a number of nearby aircraft. Further, the avoiding action to be taken can only be based on a prediction of what the other aircraft will do, this prediction being based on the assumption that it will continue to do what it has been doing over the period of observation; this assumption may clearly be unjustifiable for aircraft in an air traffic pattern. Airborne solutions to this problem seem sufficiently complex to be most unattractive. This is perhaps the hub of the question—"Why Air Traffic Control?" The avoidance of collisions must, quite fundamentally, be based not on observation of immediate history and assumption, but on *knowledge of intent*. This knowledge is available to the air traffic control organisation which can also provide itself with adequate capacity for the storage, correlation and processing of such intentions.

It has been proposed that in the *en route* phase only, there might be some advantage to be gained from a simple separation monitor which took care only of the overtaking case. This might, for example, serve to reduce somewhat the 30,000 square miles currently allotted to an individual aircraft over the North Atlantic. However, this is a somewhat special case and it would be inappropriate to argue it in the terms of this general paper on collision avoidance systems.

4. Technical Problems

The first technical consideration is the basic type of detection system to be employed. In general, three systems seem worthy of consideration, namely Infra-red, Radio and Radar—with the two latter appearing the most likely contenders.

The second basic consideration is whether the system should require active co-operation between aircraft, or whether it should be completely non-co-operative.

Taking first the non-co-operative system, this seems to imply a primary radar solution. In this case, a number of technical problems arise of which two stand out as being significant:

(a) A detection range in excess of eight miles is required. To obtain this reliably against aircraft of low reflecting area (some present-day jet air liners present reflecting areas head-on of the order of only three or four square metres) would require both a higher transmitting power and a higher aerial gain than are likely to prove attractive for airborne use.

(b) The measurement of the changes of angles of bearing and elevation of the other aircraft with sufficient precision to predict whether or not a collision risk exists is a most stringent requirement, unless the other aircraft is to be observed over an excessively long period. This is particularly true in the presence of random movements of own aircraft due to turbulence or other causes.

Alternatively, a co-operative system may be employed in which each aircraft communicates with equipment carried in nearby aircraft. While this materially eases some of the technical problems, it raises the question of reliability both from the point of view of breakdown and from the point of view of the inability to detect non-fitted aircraft. Systems in this case may use either secondary radar or the passive detection of another aircraft's transmitter. In both cases the possibility is now open that each aircraft may transmit a coded signal giving information on height, course and speed. The accuracy and detection range problems now appear manageable but even so the technical problems should not be underestimated.

Finally, there is a significant computer problem in assessing the collision risk and in calculating an escape manoeuvre, perhaps for more than one aircraft. It must be remembered that the computer can deal only with precisely defined inputs and one of these inputs must be a precise and unambiguous set of rules. Whether its output should be a direct feed to the auto-pilot or some form of recommendation to the human pilot is too large a question to discuss in a paper of this length.

5. General Comments

The problem of providing an air-to-air collision avoidance system seems intrinsically to be a formidable one. Weight is lent to this view by the very large sums of

money that have already been expended in attempts to develop such systems. In the United States, one company which had at one stage accepted contracts worth several millions of dollars for the provision of a proximity warning indicator with an expansion capability for collision warning, had to ask to be released from its contracts when the project ran into technical difficulties. Subsequently it, and two other companies, have, after considerable research and development, decided that a non-co-operative system is almost certainly impracticable. Work on co-operative systems is proceeding but certainly up to the present time no working system has emerged. It is, however, conceivable that a technical solution on these lines may be devised.

Granted the advent of a technical solution, it seems to the author that the system would still not be operationally acceptable in terminal areas or indeed in any congested air space (except possibly as an emergency safeguard). The duality of control involved and the division of responsibility seem to the author to be quite unacceptable. If aircraft were to take any substantial avoiding action in congested and controlled air space, it seems essential that they would need to seek permission from the ground control before doing so; within the times available a verbal question and answer procedure would certainly be impracticable. While it could be envisaged that permission could be sought and granted by automatic data transfer, this would presuppose that the mechanism was available on the ground for verifying the desired airborne action, in which case it would be duplicating work carried out expensively in the aircraft.

It thus seems that an air-to-air collision avoidance system would have little part to play in, or near, terminal areas and that its role, if any, would be limited to uncongested *en route* regions. It thus seems that the possible advent of such a system would tend to limit the regions *where* close control A.T.C. is needed, rather than the techniques of *how* A.T.C. should operate.

This paper has so far been entirely negative in its remarks. The author would like to close with a positive suggestion. In view of the very doubtful technical and operational possibility of air-to-air collision avoidance systems, it is the author's opinion that development effort should be devoted to improving the mechanism and procedures of ground-based air traffic control. In this field the present advances in navigational aids, in radar and particularly in data handling techniques offer a real chance of building an effective system which could shoulder fully the total responsibility for safe and reliable collision avoidance.

The Influence of Aircraft Characteristics on A.T.C. Problems

BY

B. N. TOMLINSON

(Royal Aircraft Establishment, Farnborough)

1 Introduction

To provide a basis for discussion of air traffic control problems some of the operating characteristics of long haul subsonic and supersonic jet transport aircraft are examined. Two trans-Atlantic aircraft are compared, one designed to cruise at 500 knots (Mach 0·85) and the other at 1,250 knots (Mach 2·2).

2. Low Speed Characteristics

The handling characteristics of supersonic civil aircraft at subsonic speeds will be similar to those obtained on subsonic jet aircraft. The designers' difficulties in achieving satisfactory airworthiness and operational standards will depend on the configuration chosen. For aircraft designed to cruise at about $M=2$ it is expected that the compromise between cruising and low speed performance requirements will not lead to severe stability and control problems, in fact in many ways the slender wing configurations which have been suggested are quite attractive. The most critical handling problem arises from the large rolling moments produced when side-slipping, although this may not be as severe as was once feared, and in some other respects the supersonic aircraft may be easier to fly than some of the existing subsonic jet aircraft. There are some novel problems to be faced, but they are by no means insurmountable.

At subsonic speeds the main differences in the operating characteristics of the supersonic aircraft and the subsonic aircraft arise because the former will have a higher thrust weight ratio, a lower lift drag ratio, a lower wing loading, and a lower aspect ratio. Most of the subsonic part of a supersonic aircraft's operations will take place at or below the minimum drag speed. Where precise height keeping is demanded automatic throttle control will be required to maintain speed stability, but this presents no critical problems.

In the take-off and initial climb, the higher thrust-weight ratio of the supersonic aircraft is offset by the low lift-drag ratio and the initial rates of climb are very similar to those obtained on subsonic jets. At higher speeds the lift-drag ratios of the supersonic aircraft will significantly improve and the climb performance of the supersonic aircraft will be substantially better than the subsonic aircraft. Both types of aircraft will fly noise-

abatement procedures immediately after take-off, and the initial rates of climb, using throttling to reduce noise levels on the ground are likely to be about 600 ft./min.

Both aircraft will have substantially the same approach speed, but whereas the attitude of the subsonic aircraft is substantially horizontal, the supersonic aircraft will approach at about 11° to the ground.

3. Typical Flight Plans

Before discussing the effect of operating restrictions it is convenient to look at the flight plans desired by supersonic and subsonic aircraft. In Figs. 1 and 2 the height, rate of climb, time to height and true air speed are compared along the climb and descent segments of the flight plans for a Mach 2·2 and Mach 0·85 trans-Atlantic aircraft.

3.1. CLIMB

As shown in Fig. 1 the supersonic aircraft requires about three times the distance of the subsonic aircraft to reach its cruising height but only the same order of time. Its rates of climb during the early part of the climb are about four times those of the subsonic aircraft. Transition to supersonic speeds will take place in level flight at about 36,000 ft. followed by a supersonic climb at an initial rate of climb of about 3,000 ft./min. which is greater than that achieved by a subsonic aircraft immediately after take-off. The use of reheat to improve the transition performance is likely and this will enable a more flexible transition manoeuvre altitude to be achieved. At about 50,000 ft. the aircraft will settle into a constant Mach number climb in which the altitude is increased until the optimum lift coefficient for cruising flight is obtained and the cruise climb begins. The point of transition from climb to cruise climb is not easy to define with precision and in practice will depend on the speed margins available and the detailed engineering of the engine, its intake and its fuel system.

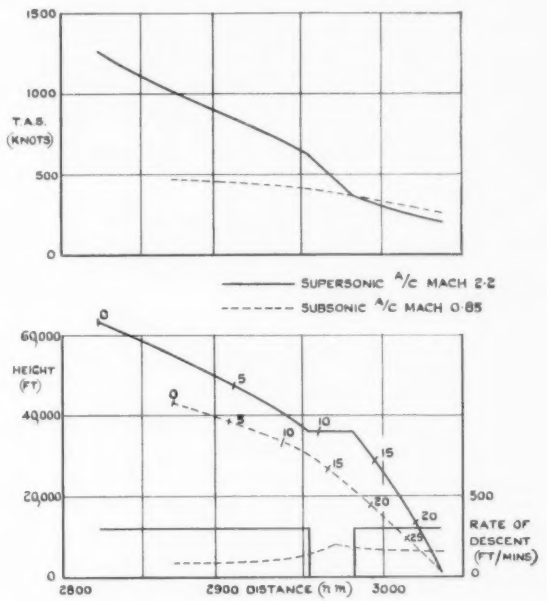

FIGURE 2. Trans-Atlantic flight plan—descent.

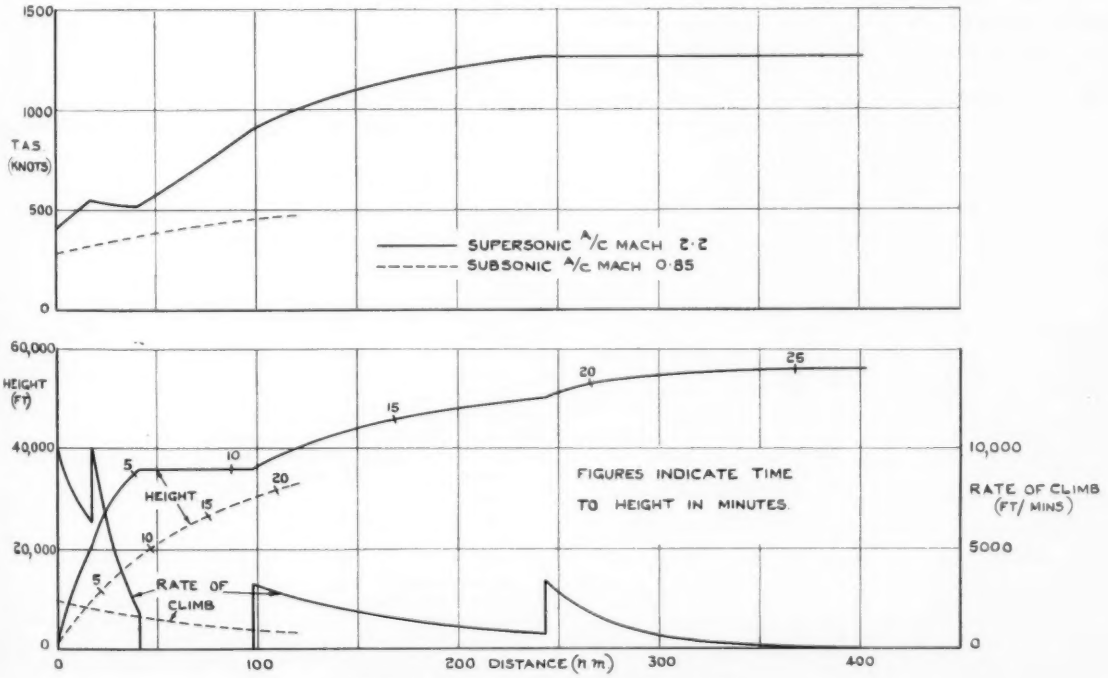

FIGURE 1. Trans-Atlantic flight plan—climb.

3.2. CRUISE CLIMB

The supersonic aircraft will start its true cruise climb about 400 miles out at an altitude of 56,000 ft. During the cruise the altitude will increase to about 63,000 ft. The subsonic aircraft will start at about 33,000 ft. and finish at about 43,000 ft.

3.3. DESCENT

In Figure 2 the supersonic aircraft is shown to require a longer descent distance but a shorter time. Its rates of descent are, however, more than twice as large as those obtained on a subsonic aircraft.

4. The Effect of Operating Restrictions on Fuel Requirements

The fuel loads required for trans-Atlantic operation by typical subsonic and supersonic jet aircraft are broken down in Table I. The supersonic aircraft carries about three quarters the number of passengers carried by the subsonic aircraft.

It will be noted that both the climb and reserve fuels required are substantially greater for the supersonic aircraft. The climb fuel is 9·3 per cent of the all-up weight supersonic and 3·4 per cent subsonic; the reserve fuel is 8·4 per cent of the all-up weight supersonic and 6·5 per cent subsonic.

The reserves quoted are an arbitrary choice. At present no rational method for estimating fuel reserves exists and in practice the operators decide the reserve level. On the supersonic aircraft the total reserves are about equal to the payload, on the subsonic they are about one-half the payload.

The effects of restricting the flight plan altitude are shown in Table II, where the increase in fuel required when operations are restricted to a level 4,000 ft. below the nominal case is given. The supersonic aircraft is much more sensitive than the subsonic aircraft. Such a restriction would mean using about 25 per cent of the reserve fuel on the supersonic aircraft and about 10 per cent on the subsonic aircraft.

Holding at various points along the flight plan has also been investigated and the results are shown in Tables III and IV. In general the fuel penalties incurred at the time of holding will be more severe at the beginning of the flight when the aircraft are operating at high weights but these will be partially offset by the consequently reduced weights at later stages. If time, rather than distance, is the determining holding factor, the most critical cases will be the supersonic climb and the cruise climb. Ten minutes hold at these points would use about 20 per cent of the reserve fuel on the supersonic aircraft and about 10 per cent on the subsonic aircraft.

The effect of restricting the cruise to constant altitude operation at various points along the flight plan is shown in Fig. 3 and is again more severe for the supersonic aircraft. If the supersonic aircraft is restricted to its initial cruise height (56,000 ft.) about 20 per cent of the reserve fuel would be used; restricting the subsonic aircraft to 35,000 ft. would use about 10 per cent.

Broadly, the supersonic aircraft cruising at about Mach 2·2 is twice as sensitive to any operating restrictions, when compared with a subsonic jet cruising at about Mach 0·85, if the extra fuel required can be met from the reserve fuel. If the extra fuel has to be found by off-loading payload, the supersonic aircraft is about four times more sensitive than the subsonic aircraft.

5. Reserve Fuels

The reserve fuels quoted in Table III are an arbitrary allotment. Ideally one would like to fix reserve fuel on a rational basis which made due provision for the probability of occurence of the various contingencies that might arise and which gave a specified overall level of safety. This safety level would depend on:

(*a*) Engine and airframe maladjustment and deterioration,
(*b*) Piloting errors,
(*c*) Air traffic control requirements,
(*d*) Equipment failure, and
(*e*) Engine failure.

TABLE I

FUEL REQUIRED FOR TRANS-ATLANTIC OPERATION

Operation	*Supersonic* $M=2\cdot2$ lb.	$\%\ W_0$	*Subsonic* $M=0\cdot85$ lb.	$\%\ W_0$
Start, warm-up and taxy	2,000	0·6	1,800	0·6
Take-off and climb to 1,000 ft.	3,500	1·1	2,100	0·7
Climb subsonic	8,000	2·5	10,200	3·4
Climb supersonic	21,500	6·8	—	—
Cruise-climb	82,500	26·2	90,600	30·2
Descent	4,000	1·3	2,100	0·7
Circuit and landing	4,500	1·4	2,100	0·7
Minimum landing reserve	2,500	0·8	2,100	0·7
Total fuel less reserve	128,500	40·7	111,000	37·0
200 n.m. diversion	9,500	3·0	8,100	2·7
45 min stand-off at 20,000 ft.	12,500	4·0	8,100	2·7
15 min stand-off at 5,000 ft.	4,500	1·4	3,300	1·1
Total fuel	155,000	49·1	130,500	43·5
All-up weight W_0	315,000	100	300,000	100

TABLE II

TRANS-ATLANTIC OPERATION

Increase in fuel required when operating 4,000 ft. below nomina altitude

Operation	*Supersonic* $M=2\cdot2$ lb.	$\%W_0$	*Subsonic* $M=0\cdot85$ lb.	$\%W_0$
Climb subsonic	−100	—	−300	−0·
Climb supersonic	+900	+0·3	—	—
Cruise-climb	+5,800	+1·8	+2,300	+0·
Total increase in fuel	+6,600	+2·1	+2,000	+0·

TABLE III

TRANS-ATLANTIC OPERATION

Effect of holding for 10 minutes at various points

Subsonic aircraft $M=0{\cdot}85$ ($W_0=300{,}000$ lb.)

Part of flight plan including hold	*Climb*	*Climb*	*Cruise-climb*	*Stand-off*	*Stand-off*
Hold height ft.	1,000	20,000	38,000	20,000	5,000
Hold Mach number	0·43	0·61	0·82	0·48	0·36
Hold fuel lb.	3,400	2,700	2,500	1,800	2,200
Increase in fuel required due to hold (lb.)					
Climb	+3,200	+2,600	—	—	—
Cruise-climb	−1,000	−800	+2,500	—	—
Stand-off at 20,000 ft.	−100	−100	−100	+1,800	—
Stand-off at 5,000 ft.	—	—	—	—	2,200
Total increase due to hold lb.	2,100	1,700	2,400	1,800	2,200
Total increase due to hold % W_0	0·7	0·6	0·8	0·6	0·7
Total increase due to hold % W_0 (for typical supersonic aircraft)	1·0	0·9	1·8	0·9	1·0

Ideally one would also like to compare the implications of air traffic control requirements on fuel loads with aircraft offering roughly the same level of safety. The fuel reserves quoted in Table I have not been obtained in this way but a check has been made on the *en route* engine failure cases. It would appear that the failure of one or two engines on a four-engined subsonic aircraft is about as critical as the same number of engines failing on a six-engined supersonic aircraft.

6. Manoeuvrability

At subsonic speeds the stability and control characteristics of supersonic aircraft are unlikely to be radically different from those obtained on current subsonic jets. In some ways they may be better. At supersonic speeds the effects of time lags will be much more significant.

The simple kinematics of manoeuvres in the horizontal plane are indicated in Fig. 4. A given angle of bank or total normal acceleration will give a radius of turn directly proportional to the square of the speed. At subsonic speeds the radius of turn is unlikely to exceed 10 miles for either aircraft—at 500 knots this implies a very gentle manoeuvre with an angle of bank of about 20° and a manoeuvring acceleration of $0{\cdot}065\ g$. At Mach $2{\cdot}2$ the same manoeuvre would give a radius of turn of about 60 miles and even a fairly violent manoeuvre with an angle of bank of about 45° and a manoeuvring acceleration of $0{\cdot}4\ g$ would give a minimum radius of turn of about 25 miles.

The paths of the aircraft in plan view for level turns at $1{\cdot}2\ g$ and various true speeds are indicated in Fig. 5 where the distances covered in a given time are also shown. Although manoeuvres at supersonic speeds are not likely to be very popular, or practicable, in view of the much earlier warning required, the ability to get well away from any congested or dangerous region in a very short time may be of some value.

TABLE IV

TRANS-ATLANTIC OPERATION

Effect of holding for 10 minutes at various points

Supersonic aircraft $M=2{\cdot}2$ ($W_0=315{,}000$ lb.)

Part of flight plan including hold	*Climb*	*Climb*	*Climb*	*Cruise-climb*	*Stand-off*	*Stand-off*
Hold height ft.	1,000	20,000	40,000	60,000	20,000	5,000
Hold Mach number	0·62	0·90	1·72	2·20	0·65	0·47
Hold fuel lb.	5,300	4,800	9,000	6,700	2,700	3,000
Increase in fuel required due to hold (lb.)						
Climb subsonic	+5,000	+4,600	—	—	—	—
Climb supersonic	−600	−500	+8,400	—	—	—
Cruise-climb	−1,000	−900	−2,200	+6,200	—	—
Diversion	−100	−100	−200	−200	—	—
Stand-off at 20,000 ft.	−200	−200	−300	−300	+2,700	—
Stand-off at 5,000 ft.	—	—	−100	−100	—	3,000
Total increase due to hold lb.	3,100	2,800	5,600	5,600	2,700	3,000
Total increase due to hold % W_0	1·0	0·9	1·8	1·8	0·9	1·0
Total increase due to hold % W_0 (for typical subsonic aircraft)	0·7	0·6	—	0·8	0·6	0·7

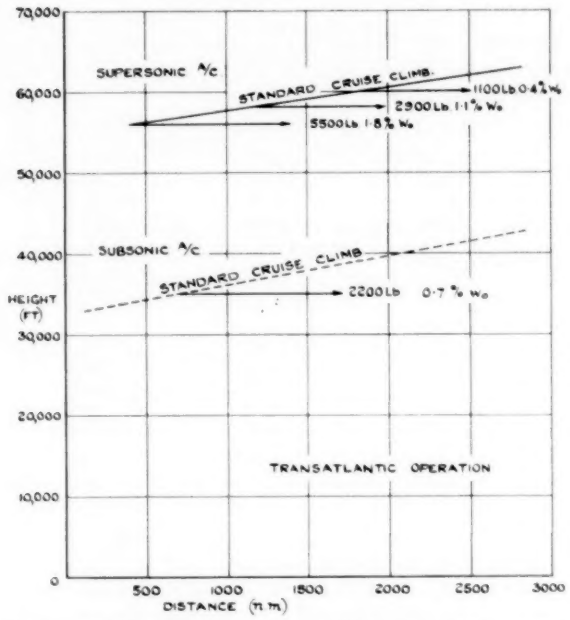

FIGURE 3. Fuel penalties due to altitude restrictions on the cruise.

A 40 per cent increase in thrust is required to maintain constant speed in a level turn for a supersonic aircraft performing a 1·4 *g* turn. This looks at first sight excessive, but a subsonic jet would also require about 30 per cent increase in thrust. Thus it would seem that the manoeuvrability of both subsonic and supersonic aircraft is likely to be restricted by engine thrust in the cruising condition and that 1·2 *g* turns are likely to be the most violent manoeuvres that can normally be tolerated. If excess engine thrust is not available, even under emergency rating, and if it is desired to maintain speed, the initial rates of descent will be much higher for the supersonic aircraft. As height is lost the rates of descent will diminish rapidly. The loss of height which might be faced in a prolonged turn at constant speed is substantially independent of speed.

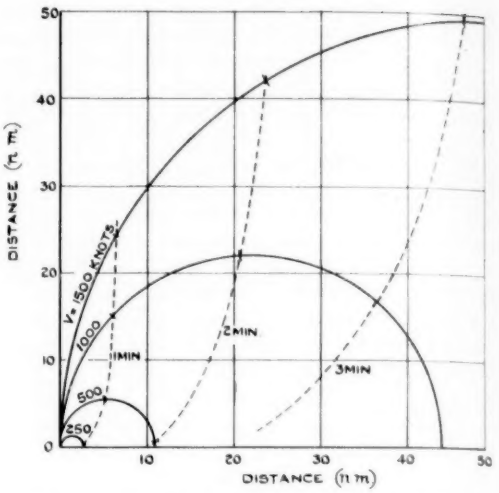

FIGURE 5. Turning performance—level flight. $n=1{\cdot}2$; angle of bank $=34°$.

7. Collision Avoidance

The preceding remarks are mainly concerned with the steady manoeuvre for which the pilot has had adequate warning. Collision avoidance manoeuvres, in the horizontal plane, for both types of aircraft are shown in Fig. 6. Zooms or bunts can be used to avoid collision and may be extremely useful, although more uncomfortable to the passengers. The collision avoidance performance in banked turns would seem to be the most

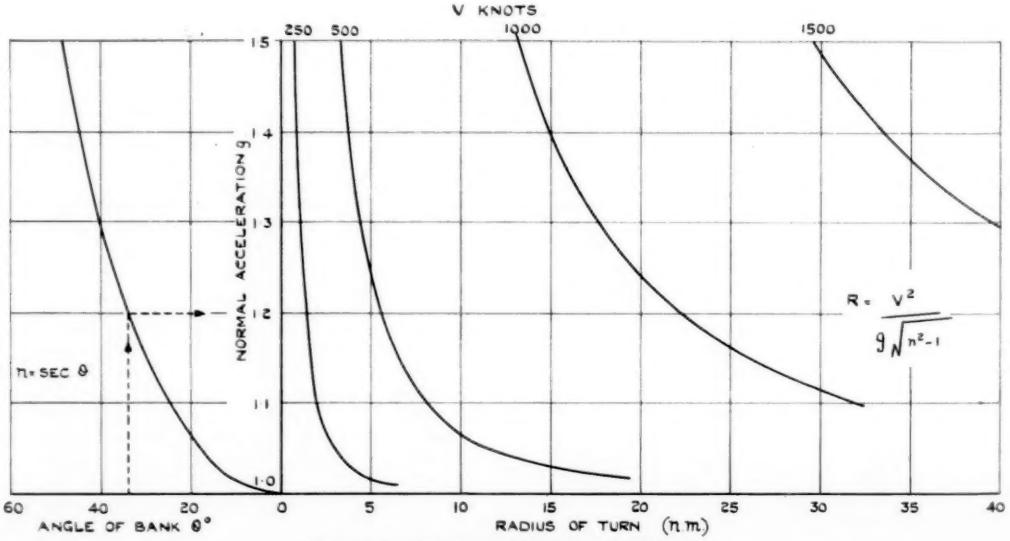

FIGURE 4. Turning performance—level turns.

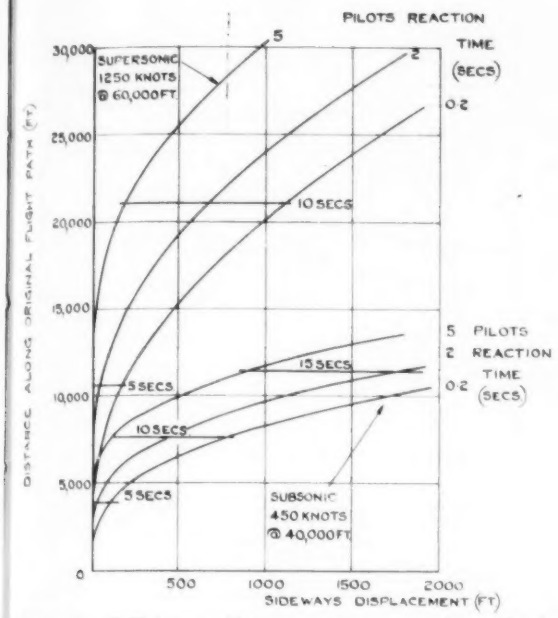

FIGURE 6. Collision avoidance manoeuvres maximum bank angle 45°.

useful yardstick for comparing the two types of aircraft. The transition into the manoeuvres shown in Fig. 6 assumes maximum aileron angles of about 20° and a maximum angle of bank of 45°. The subsonic aircraft can achieve 45° bank in about three seconds and the supersonic aircraft in about 1·5 seconds. It would appear that pilot reaction time is likely to be more important than aerodynamic response in collision avoidance manoeuvres.

8. Separation Requirements

Since the supersonic aircraft will fly at much higher speeds its position keeping along the track should not be unduly affected by changes in the external environment. In many ways, *e.g.* the short flight time and insensitivity to head winds, the supersonic aircraft may be easier to control than the subsonic aircraft. Lateral divergencies from the track due to navigation errors will, however, increase linearly with speed.

It would appear that a stage has now been reached when a worthwhile study of separation requirements can be undertaken, but it is unlikely that the aircraft characteristics will play a dominant role in fixing these standards.

V.T.O.L. and S.T.O.L. Aircraft and Helicopters and the System of Air Traffic Control They Will Require

BY

J. K. B. ILLINGWORTH

(Royal Aircraft Establishment, Bedford)

1. Introduction

The title of this paper is "V.T.O.L. and S.T.O.L. Aircraft and Helicopters and the System of Air Traffic Control they will require," but it does not set out to give an audience of Air Traffic Control experts a lecture on how they will have to run their business in the future. What it does do is to make a few remarks on how the operators will wish to run these types of aircraft, when they have them, and to draw some inferences about the new problems in Air Traffic Control which will have to be solved as a result.

One point which may vitally affect the operation of all these types of aircraft is noise, but this is not discussed. Instead it will be tacitly assumed throughout that noise problems will have been overcome before these aircraft go into service.

2. Operating Characteristics

2.1. V.T.O.L. AIRCRAFT

V.T.O.L. aircraft, of course, cover a wide range of types, varying from jet-lift aircraft such as the Short SC.1 or Hawker P-1127 at one end of the scale through fan-lift aircraft, deflected slip-stream and tilt wing types to the tilting rotor aircraft which border on helicopters. All these have one characteristic in common: they cruise as normal aeroplanes and at some point quite late on in the sequence of events leading up to touch-down, they begin a transition during which they change over from wing-borne flight to engine-borne flight and reduce their forward speed correspondingly from a fairly normal aircraft approach speed to something near zero.

This process can be accomplished in quite a short time and distance. A jet-lift aircraft starting a landing

transition at 140 knots and decelerating at 0·25 *g* takes 30 secs. and 1,200 yds. to come to rest. Further, the exact shape of the path which it follows during the transition is not important. Calculations made of the variation in the amount of fuel used by such a jet-lift V.T.O.L. aircraft in transitions along various paths and using various techniques show that within reason the amount of fuel used does not vary greatly around ½ per cent A.U.W. The important point is that the transition should end, and that it should end in the right place. If jet-lift is to be an economic proposition the fuel weights used during landing must be minimised and once a transition starts the aircraft must be regarded as being committed to a landing. Also, hovering with the aircraft entirely jet-supported is an expensive procedure, and so is the correction of errors and the final selection of a touch-down point with the aircraft hovering. Flight tests on the "Flying Bedstead" with the pilot moving the aircraft between points a mere 80 yds. apart as rapidly as possible together with a 90° turn and a descent of 40 ft.—and using some distinctly uncommercial attitudes in the process—showed that such a manoeuvre would use as much fuel as the whole of a landing transition.

It was stated above that the exact shape of the path used for a landing transition is unimportant. There are, however, limits to the paths which it is practicable to use. Generally speaking, the angle of descent in the first half of a transition will not exceed about 10°. A straight line path at this angle all the way to touch-down is practicable, as is a straight line at a small descent angle to begin with, but with a much steeper final descent. Alternatively a parabolic path may be advantageous in combining a small initial angle of descent and a steep final angle without any discontinuity, while a hyperbola might also combine these advantages with an attractiveness to the radar designers but at the expense of some kinematic complication.

So far the characteristics of jet-lift aircraft have been mainly considered. Other types have as yet been given less consideration in this country. However, the statements made apply almost equally well to fan-lift aircraft although the comments on hovering fuel consumption have then slightly less force, while as the other V.T.O.L. types with lower and lower efflux velocities are considered, hovering time becomes of less and less importance. Other important changes in characteristics also occur. Jet-lift aircraft can be operated independently of wind direction but it is at least possible on our present knowledge that deflected slip-stream and perhaps tilt wing aircraft will have to be operated into wind. Ground effects must be mentioned but should not be over-emphasised. Jet-lift aircraft are normally landed on, and have been taken off from, plain concrete.

2.2. HELICOPTERS

While helicopters are V.T.O.L. aircraft on strict definition, they differ fundamentally in that they are always engine-borne and do not have to perform a transition manoeuvre between cruising and hovering flight. As far as Air Traffic Control is concerned, the essential features of the helicopter appear to be its independence of wind direction, its low fuel consumption compared with a hovering jet-lift aircraft—of the order of four per cent—and its ability to approach at a constant angle of up to 20° or so.

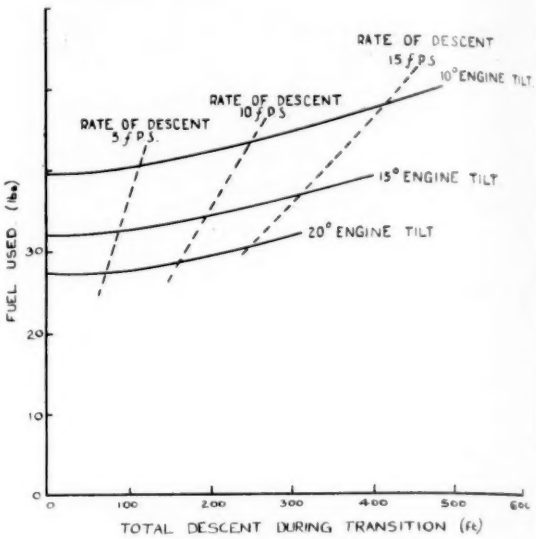

FIGURE 1. Variation of fuel used with total descent. Constant rate of descent transitions.

2.3. S.T.O.L. AIRCRAFT

S.T.O.L. aircraft, unlike V.T.O.L. aircraft and helicopters, are not susceptible of precise definition: I shall use the term to cover aircraft which use circulation control of some form, usually together with high power-weight ratios, to obtain not only short take-off and landing runs but also, steep approach and climb away paths compared with conventional aircraft. Away from the ground their normal cruising speeds and altitudes will be much the same as those of conventional aircraft and they will be capable of operating as conventional aircraft when large aerodromes are available. As far as Air Traffic Control is concerned their principal feature is the ability to operate into and out of small areas, but only into wind.

3. Effects of these Characteristics on Air Traffic Control

3.1. GENERAL

From what has been said it is fairly clear that V.T.O.L. and S.T.O.L. aircraft in cruising flight will not necessarily present Air Traffic Control organisations with any new problems, while helicopters, with their low cruising speeds at low altitudes merely fill an ecological niche which is at present vacant. In the immediate vicinity of the airport, however, the capabilities of V.T.O.L. aircraft and helicopters will present not so much problems as possibilities which may make Air Traffic Control easier, and not more difficult, if they can be utilised. The operation of aircraft which are independent of wind direction, which

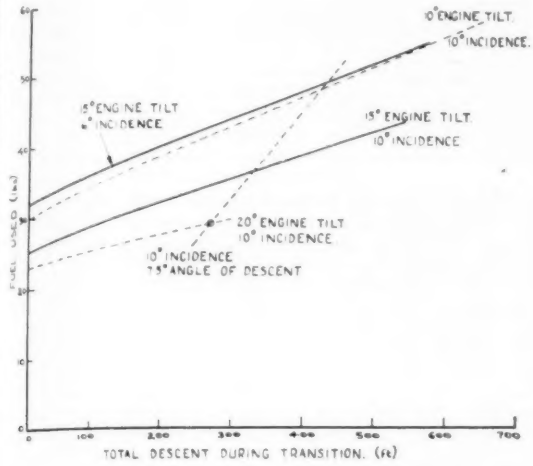

FIGURE 2. Variation of fuel used with total descent in straight line transitions.

land at and take-off from the points where they load and unload their passengers and which need not taxi has obvious possibilities, but if full advantage is to be taken of them Air Traffic Control must be capable of working down to a smaller scale of distance. It will no longer be sufficient to know where an aircraft is to a mile or so: it may well be necessary to know to 50 ft.

Two cases may be distinguished which present different Air Traffic Control requirements, according to whether V.T.O.L. aircraft and helicopters are being operated by themselves, or whether conventional aircraft are also being operated from the same airfield.

3.2. OPERATION WITH V.T.O.L. AIRCRAFT ONLY

Operation with V.T.O.L. aircraft and helicopters only should initially be a relatively simple procedure, since in the immediate future an airfield handling only such traffic is unlikely to deal with high traffic densities. When high densities of V.T.O.L. traffic are reached, the area involved will also be large. A V.T.O.L. airport handling the traffic which London Airport handles today will require much of the area of London Airport purely for "parking area"—hangarage, passenger handling area and so on. Air Traffic Control will then need to be developed to handle aircraft approaching at short intervals from the same direction—in effect landing on parallel runways—in order to avoid uneconomical "stacking."

Such a procedure will be made easier by the requirement that for economy V.T.O.L. aircraft must aim to end their transitions at the points at which they will touch down. This does not necessarily mean a very high accuracy, but it does mean a good deal better accuracy than is required of the touchdown point of a conventional aircraft, and if the pilot is to do this every time, even in conditions of poor visibility, his task will be made much easier by some form of radar guidance. This need not be particularly complex, but will probably involve a local fixing system which will enable the pilot to know exactly where he is relative to this desired touchdown point and which conversely will enable Air Traffic Control also to know precisely where the aircraft is.

Where S.T.O.L. aircraft are also concerned the position is rather different. An airfield operating only S.T.O.L. aircraft is in much the same position as any current airfield with the same traffic density, but one where S.T.O.L. and V.T.O.L. aircraft are mixed has the same problems as one where V.T.O.L. aircraft and conventional aircraft are handled.

3.3. OPERATIONS WITH OTHER AIRCRAFT

When, however, we consider simultaneous operation of V.T.O.L. aircraft and conventional aircraft the problem of taking advantage of the peculiar abilities of the former is more difficult. Simply to operate the two together would not be particularly difficult. Apart from helicopters, V.T.O.L. aircraft could be treated as normal aircraft until the last stages of the approach when, instead of touching down at 120 knots or so, they would perform transitions and touch down vertically. Helicopters which could not mix in the main traffic stream would have to be kept to the lowest height band out of the way of other aircraft and allowed to cross traffic streams only under strict supervision. Such a system could work, but would be in many ways an admission of defeat, particularly since the necessity for providing fuel reserves for time spent being stacked or otherwise delayed before landing might turn the scale between economic and uneconomic operation of V.T.O.L. aircraft.

Under these circumstances, therefore, a system is really required which could separate the V.T.O.L. from the conventional aircraft and allow them to descend and land on separate tracks. This means in effect a separate pattern for V.T.O.L. aircraft with finally almost simultaneous use of two parallel runways—one on the ground and one in the air—with a suitable horizontal separation.

In these circumstances S.T.O.L. aircraft will have to be included with the conventional aircraft since they will have to be operated on to the same runways. They then present neither new problems nor new advantages.

4. Conclusions

To sum up, the principal new feature which Air Traffic Control will have to adopt when V.T.O.L. aircraft and helicopters come into general use will be an ability to work to much greater accuracy in the neighbourhood of airports. In normal cruising flight they will not present any new problems.

The principal difficulty which Air Traffic Control will have to overcome will be finding a method of separating vertical landing aircraft from other aircraft at major airports, and finding air space in which to do this. If this can be done and if some form of close control can be adopted, the introduction of V.T.O.L. aircraft may make Air Traffic Control easier rather than more difficult.

Summary of Discussion

BY

E. T. HANLEY AND H. KEELING

(*Ministry of Aviation*)

IMPROVED NAVIGATIONAL AIDS

Captain Turner and Captain Percy, G.A.P.A.N., stressed the need for better navigational aids to be provided as soon as possible, with particular regard to the London Terminal Area. Group Captain Veal replied that, while the United Kingdom's short range navaid policy had had an effect on VOR provisioning, a programme to provide a total of 38 VORs and TVORs was now being implemented. Seven VORs were already in operation; five others were installed and would shortly become operational. TVORs defining Epsom and Watford were due to be operating before the end of the year and six Scottish TVORs were expected to become operational by June. Siting requirements for this type of aid were critical and the major problem was getting access to the lands at the limited number of suitable sites which could be found. Action was proceeding with a view to clearing the way for installation of the remaining equipments as quickly as possible.

Captain Percy referred to the importance to A.T.C. of aircraft height information and asked if it were proposed to provide this information on the radar screens. The Chairman said the requirement for the Controller to have instantaneous height data was fully appreciated. Three-dimensional long range radar was extremely costly and he did not foresee the possibility of obtaining such equipment for A.T.C. purposes only. The intention was to relay height information on to the radar screen by data link through the secondary radar system. Development was proceeding and there might also be a separate automatic data link available for the future.

Captain Percy was concerned that the Controller might not be able to detect aircraft not equipped with transponder beacons if their responses on the screen were obscured by SSR data from equipped aircraft. He believed that all aircraft should be required to have responder beacons. The Chairman said it was first necessary to ensure compatibility of SSR systems with the military and with other States. Progress to agreed specifications was being achieved through I.C.A.O. and, in particular, with the U.S.A. and trials were being made at London Airport.

LIAISON BETWEEN CIVIL AND MILITARY CONTROLLERS

Captain Turner said that, in the course of a recent visit to the Southern Air Traffic Control Centre, he had observed that the R.A.F. radar unit there was in a separate building from the civil radar unit and that there did not appear to be even a telephone link between them. He urged that there should be the closest possible liaison between civil and military Controllers at joint A.T.C. Units.

Air Commodore Russell and Air Commodore Hickey replied that the transfer of the R.A.F. radar unit to the main Southern Centre building was to be completed within a few days. There was in fact telephonic communication between the Controllers and additional methods of effecting closer liaison were to be provided. Ways and means of fitting the military radar positions into the Operations Room were being re-examined but the difficulty was the restricted space available. In the new A.T.C. Centres, the civil and military Controllers would be in the same rooms with full liaison. This had been achieved at the three joint units providing a radar service in the upper air space and the arrangements at these units were working well. Reasonable progress had been made towards meeting the requirement.

CONTROLLER FATIGUE AND WORKLOAD

Captain Hunt, referring to Mr. Field's Paper, recalled the studies carried out at the Southern A.T.C. Centre some years ago by the Cambridge Medical Research Unit. He believed that one conclusion reached from these studies was that mistakes were liable to occur when a Controller was under a light load during a quiet traffic period. He asked if experience confirmed this conclusion. Mr. Field replied that the relationship between workload and errors was a difficult pattern to follow. He agreed that mistakes sometimes occurred at quiet times and thought the explanation was that at peak periods the Controller got into a rhythm and worked at top speed and efficiency. He considered there should be more fundamental research on Controller stress fatigue. Mr. Mundy, A.T.C.O. (Air Traffic Control Officer) Ministry of Aviation, said that he was one of the Controllers who took part in the tests. They had shown that mistakes occurred not only when traffic was light but also at busy periods when the data was presented to the Controllers in a difficult manner.

Captain Powell, G.A.P.A.N., referred to Mr. Field's statement on the similarity of the stresses experienced by pilots and Controllers. He wondered whether regulations regarding maximum hours of duty and minimum rest periods to guard against fatigue were laid down for Controllers as they were for pilots. Mr. Field replied that a code of behaviour before coming on watch had not been found to be necessary. Controllers were conditioned to set hours of watch but occasions did arise when, to maintain a full A.T.C. service, these hours had to be exceeded.

Mr. Haines, G.P.S. Ltd., said the capacity of an A.T.C. system was limited more by the rules which the Controllers had to apply than by the difficulty of their jobs. He asked whether the point of automatic techniques was to ease the Controllers' workload or to increase the capacity of the system by allowing the rules to be altered. If the rules were to be altered, more information would have to be assimilated by the Controllers. Merely presenting the information to them would not permit the system capacity to be increased. He suggested that to achieve this the automatic techniques would have to take over some tasks, including routine decision making, from the Controllers. Group Captain Veal replied that the purpose was partly to increase the capacity of the system and partly to deal with the problems which arose from developments in aviation itself. Mr. Field considered that automation should help increase capacity and ease the load on Controllers.

Mr. Anast said that in the U.S.A. and, he suspected, elsewhere, A.T.C.O.s were an elite corps with high morale, due entirely to their having a heavy responsibility and workload. The Controllers had had to hold the fort while technology in the A.T.C. field had lagged some ten years behind. Control was now about to develop from an art to a science. Mr. Arney, Third U.S.A.F., thought there was insufficient recognition by the public of the A.T.C.O.'s responsibilities. Wider publicity would help recruitment.

Mr. Field agreed that A.T.C.O. morale was high and endorsed Mr. Anast's statement. He also agreed that public relations had probably been rather neglected. This was possibly due to the fact that the complexities of the Controller's tasks were difficult to put across to the general public. He said that pilots had established themselves as a profession and A.T.C.O.s were now striving to obtain the same recognition. The Chairman said wider publicity was being given to the U.K. A.T.C. Service, for example the recent demonstration to the Press of the upper air space service provided from the joint radar unit at Bishop's Court.

Captain MacEwan, G.A.P.A.N., praised the standard of A.T.C. service provided in the London control zone. He

thought that this was due to the high calibre of the Controllers rather than to the A.T.C. system and aids.

Captain MacEwan went on to say that he was concerned to hear that TVORs of limited range were to be used at Epsom and Watford. He believed these should be replaced by VORs. Group Captain Veal said that TVORs had a range of at least 50 miles and were specially designed as terminal and not main *en route* navigational aids. There would be VORs in the area as main aids to mark the airways.

Mr. Field thanked Captain MacEwan for his tribute. He referred to the strong bond which had grown up in the U.K. between A.T.C.O.s and pilots, each being able to trust the professional ability of the other. Mr. Slocombe said that the airline operators had to take account of all the countries on their network. Controllers in some States were very poorly paid and had to put up with bad conditions. This had a detrimental effect on the standard of A.T.C. service provided.

CIVIL/MILITARY ORGANISATION

Air Marshal Sir Charles Guest said that the civil/military issue was the most important one in the A.T.C. field. A feeling of conflict had grown up between the two sides, although a great improvement was now evident. This conflict had originated largely from the fact that the deployment of military airfields had been fixed before the growth of civil flying after the war. The requirements for airways and other controlled air space had led to restrictions on the military and competing needs for air space usage. It was essential to maintain the right perspective and to recognise that the Services needed reasonable freedom of operation to fulfil their responsibilities towards defence. The importance of A.T.C. had only recently been appreciated in the R.A.F. Much had now been done and the setting up of the R.A.F. U.K. Air Traffic Service enabled joint planning to take place. He was sure that greater knowledge of each other's requirements would lead to better understanding. He endorsed the praise which had been given to the A.T.C.O.s and said it was essential that they should have incentives in the way of salary and promotion structures. Finally, he urged that more visits should be paid by pilots to control units so that they could see there what was being done to ensure their safety.

Captain Percy referred to the concept of a single control system and asked how the organisation envisaged for the United Kingdom differed from that which had been introduced in the U.S.A. Mr. Anast said he firmly believed there should be one control system for each air space. For this reason the U.S.A. had changed to a single A.T.C. authority. Captain Hunt said the important requirements were to have a common A.T.C. policy, common standards of competency for A.T.C.O.s and clearly defined procedures so that each Controller knew what he had to do. The A.T.C. Board was developing the common policy, training standards had been established and common procedures laid down. A joint radar school was operating at Sopley and the use of joint A.T.C. radar units, already working well to provide an upper air space service, was being extended. The A.T.C. Board had set up a high level national planning group to make recommendations on the future civil/military A.T.C. organisation. The planning group had visited the United States to study the system there and its report was now awaited. The Chairman summed up this part of the discussion by saying that the U.K. was moving towards a new era and the two major issues, civil/military A.T.C. and the future control system, were receiving intensive study. He was confident that the outcome would be satisfactory.

LIAISON BETWEEN CONTROLLERS AND OPERATORS

Mr. Petts, who introduced himself as a junior Controller, pleaded for better liaison between working Controllers and the operators. He had attempted to arrange local liaison flights with the companies at his aerodrome in order to familiarise himself with A.T.C. procedures from the pilots' viewpoint, but without success. Air Commodore Hickey agreed that there was a great need for co-operation and personal contact. He mentioned that a liaison scheme between the R.A.F. and B.E.A. had recently been introduced. The Chairman also referred to the excellent interchange facilities which existed between the Ministry of Aviation and the Corporations from which great benefit had been derived.

AIR MISSES

Mr. Slocombe, questioned on the causes of air misses, said that A.T.C. errors were responsible for a very small proportion. Many incidents had arisen through there being both IFR and VFR traffic in the same air space. However, during 1960 there had been a dramatic drop in the cases reported by B.E.A. pilots, possibly because of increasing adherence to IFR. He considered the elimination of VFR flying in controlled air space would lead to a significant reduction in the number of air misses. A number of incidents occurred in the vicinity of aerodromes where approach paths were not protected from uncontrolled traffic. The Chairman said that all air miss reports were carefully investigated. The number in which a degree of hazard was found to exist was very small indeed.

RESEARCH AND DEVELOPMENT FLYING

Mr. Pearson, S.A.T.C.O. Farnborough, said that he had understood that the improvements referred to by Group Captain Veal in his paper concerned controlled air space. He asked what was being done to protect traffic, such as research and development flying, which used the flight information regions. Mr. Pike, de Havillands, was also concerned with this matter from the contractor's flying viewpoint. Group Captain Veal replied that the State had a responsibility for all air space in the flight information regions and not only controlled air space. The aim was to develop the A.T.C. system to remove the existing restrictions so far as possible and to extend protection from collision to all movements. Captain Hunt said that, with the amalgamation of the two Ministries concerned with civil flying and with research and development flying, the new Ministry of Aviation was now seeing what provision could be made for Contractors' and Establishments' operations. There were a number of airfields around the country which provided radar surveillance for their own aircraft and this situation required to be tidied up. The first task was to make sure that the radar controllers at these airfields were fully competent and this was being done through the introduction of a licence system with radar ratings. It might be necessary to have some form of master radar control centre for each area and developments such as this would be discussed with the contractors.

FLIGHT PROGRESS BOARDS

Mr. Hansford said he had understood from Mr. Field that controllers were already inundated with different kinds of information. Referring to Mr. Anast's remarks concerning the need for improved flight progress boards, he asked whether the flight progress board would ever be able to display all that the controller required, particularly in view of the need to co-relate information from SSR, data links and other sophisticated aids in the future. Mr. Anast replied that, assuming an environment of aircraft not fundamentally different from that already met today, the flight progress board, together with something in the nature of a tagged display to show the controller the position of aircraft, was probably all that would be required. With the advent of automatic air/ground data links, however, he visualised that these would have to "talk" to a computer and not directly to the A.T.C.O. Mr. Pike said that controllers did make sense out of all their displays. He thought there ought to be something better than a flight progress board but no one knew yet how to do it. It had been said that it was rather important to be careful how one altered the habit pattern of skilled professional men.

PLANNING AND COMPUTERS

Mr. Haines referred to Mr. Anast's statement that in the Chicago/Indianapolis upper control area an average of only three movements per watch required control intervention.

He asked whether there was a planning function in this area control exercise and, if so, what this function was. Mr. Anast replied that there was a planning function, although not too much attention was paid to forward planning, the emphasis being placed on monitoring progress through the area by means of radar displays and SSR. A speaker from Elliott Automation, said that what he had heard so far had led him to believe that A.T.C. was trying to handle "M1" traffic on country lanes and he was worried about the problem of controlling fast aircraft in the same air space as the slower ones. He considered that the air-space was not being utilised properly and that a solution based on the help of computers offered great possibilities. There ought to be rethinking on the whole problem with the object of providing a system of planned collision-free flight. Mr. Anast replied that he believed complete pre-flight planning as a basis for developing an all-embracing air traffic control system was a big trap. Full account had to be taken of the characteristics of the vehicle requiring to be controlled. At the present time experience had shown that it was not worthwhile to plan ahead beyond 30 minutes. He recognised that, while a monitoring system might be sufficient in low density areas, a more rigid separation pattern was essential in high density areas such as TMAs.

Mr. Sparks, Automatic Electronics and Telephone Company, asked what was the reliability of computer systems needed for A.T.C. and what would the procedure be if the "central machine" failed. Also, how would a reserve computer be brought into action and if triplication were used to guard against unreliability, how would it be decided which machine was right if there were differences between the three. Mr. Anast agreed that there was a need for a standby, but did not consider that complete duplication all the way through the system was necessary. He stressed that full reliance could not be placed on reliability and therefore the system would have to be designed to ensure that, in the last resort, human controllers could recapture the situation and keep it running, albeit at a less rapid rate.

NEED FOR NEW TECHNIQUES

Air Marshal Oulton expressed disappointment that the papers read had been concerned with the elaboration of existing techniques and that no really new thinking had been put forward. He referred to the statement that traffic spent eighty per cent of its time over the U.K. in climbing and descending. He believed that, in order to avoid unnecessary restrictions to other movements, the possibility of having inclined airways should be studied. Air Commodore Hickey was also rather disappointed in having heard only about fixed route systems. He referred to the possibilities of collision in the flight information regions and wanted to know more on whether automation and electronics were going to make possible the exercise of control on an area basis. He mentioned that the experience recounted by Mr. Anast for the Chicago upper air space control area was similar to that in the U.K. in that the number of occasions in which control intervention had to be made was, so far small.

Mr. Pike thought it necessary to define what was meant by "area control." To some people it meant a free-for-all but if this were to be so, a computer the size of an airport would be required. He suggested that the correct definition was ability to follow a multiplicity of routes, instead of a fixed route system, and to control all aircraft that could or would co-operate. He believed that, if this system were to be adopted, computers and automatic techniques could cope. Mr. Anast agreed with this definition, but repeated that, while at high level a pure form of area control should be possible, as one got lower, then route structures and stratification were essential. Mr. Bayne, ICT Special Projects, suggested that radar might not be the best means of getting accurate position and velocity information on aircraft. Mr. Anast agreed but pointed out that some means exterior to the aircraft were needed to guard against airborne failures.

COLLISION AVOIDANCE SYSTEMS

Mr. Wilde was not convinced by the conclusion in Mr. Hansford's Paper as to the impracticability of airborne collision avoidance systems. Mr. Anast said that while it was difficult not to support the development of such systems, as an adjunct to safety, he did not think it would be practicable to rely on them in dense traffic areas. In areas such as the London, New York and Chicago T.M.A.s, traffic density would be such as to cause collision avoidance systems to trigger off all aircraft into anti-collision manoeuvres, with the result that no aircraft would land.

TRAINING OF A.T.C. OFFICERS

In answer to questions on the subject of controller training, Mr. Field explained that synthetic equipment was used at the A.T.C. School at Hurn to portray the system that controllers use in practice. He thought training methods were effective but stressed that continuation training was a necessary part of a controller's life. Air Commodore Hickey described the use of synthetic radar trainers at the joint school at Sopley for training on area control alongside the operational controllers dealing with the upper air space. He said a trainer was needed to generate synthetic tracks which would be accurate and could hold accuracy with introduced manoeuvres. Captain Hunt said that, before any changes were made in the system, controllers were given thorough training in the new procedures. He referred to the computer and associated equipment to be installed at the Ministry's Air Traffic Control Experimental Unit for evaluation of automatic techniques. An essential corollary to the evaluation of the system would be the training of personnel in its operation before introduction into service. This would continue to receive careful attention as each stage of automation was introduced.

ESTIMATES OF FUTURE TRAFFIC AND PARALLEL RUNWAYS

Air Commodore Hickey said that a fundamental part of the exercise of designing an A.T.C. system should be the assessment of the capacity to be handled and the nature of traffic involved. He suggested there was a need for a group to look into the future estimates of how many aircraft would be involved, where they would want to go to, and what types of aircraft would be operating. Captain Hunt agreed with the need for accurate and comprehensive estimates on traffic and said that the R.A.E. Mathematical Services had been asked to work on this problem. They had already produced a mathematical model of traffic in respect of the North Atlantic. On the question of statistics generally a section was being established at the Ministry to collect and analyse data to provide a firmer basis for planning. He referred to the Eurocontrol Census of traffic in the upper air space, which was taking place shortly.

Mr. Anast said a "snapshot" of all aircraft flying in the U.S.A. on a July afternoon now would probably show a count of 8,000 aircraft of which 2,000 would be flying under IFR. By 1965 these figures would be doubled. Of those not flying IFR, *i.e.* not under control, many would be doing local circuits and bumps around small airfields and could adopt the technique quite safely of "seen and be seen." A further proportion would be flying cross-country, low and slow, and could be regarded in the same category. This would leave about 6,000 of the total to be tracked so that they could be controlled. Three dimensional information on all this traffic would be needed and for this purpose altitude coding offered great possibilities.

Continuing, Mr. Anast said that growth in the terminal areas did not follow precisely the same rules. Traffic was, of course, very heavy and he thought that saturation point would first be reached in regard to runway capacity. Parallel runway operation was needed and there was every hope of getting satisfactory operation in IFR on parallel runways down to a distance apart of 3,500 ft. Captain Hunt stressed that the operation of parallel runways simultaneously for landings would require the utmost co-operation between airports and their traffic control authorities on the one hand and pilots and operators on the other. Studies had begun in the U.K. on parallel runway operation for landings at London Airport and trials would be held in the fairly near future.

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THE ROYAL AERONAUTICAL SOCIETY
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Technical Department

The Society's Technical work commenced in 1940 with what were then known as Stressed Skin Data Sheets. During the years that followed other subjects were added and the Royal Aeronautical Society Data Sheets became known and used, throughout the world, as up-to-date authoritative statements on aeronautical technology and as useful tools in the many processes of aircraft design.

In recent years the demands upon the Society's Technical Department have increased most markedly. The activities, which may best be described in general terms as the synthesis of design and analytical procedures, have been required to increase in scope and volume and the field of application of the work has extended as the use of techniques originally developed for aeronautical purposes has extended into many technologies. This is a reflection of the important changes taking place in the organisation of the research-design-production process throughout the world; the application and correlation of the vast amount of information resulting from the present high level of research activity is exercising the thoughts of many organisations both National and International. Clearly there is an interesting future for any activity which assists this process and the Royal Aeronautical Society's contribution is becoming particularly important in view of the Society's experience and the pioneering role which it has played.

The most recent request from official quarters for extension of the work of the Department concerns a study of aerodynamic data appropriate to the high subsonic and transonic flight regimes; over a long period the extension of this work to higher speed ranges may be anticipated. A new group within the Department is undertaking the work and there are vacancies for engineers of varying experience in this group. In particular, in addition to junior engineers who are engineering or science graduates with experience of high speed aerodynamics, the Society is most anxious to obtain the services of a senior engineer. Such an engineer should be a graduate, be completely familiar with the interpretation and application of aerodynamics data appropriate to high subsonic speeds and, preferably, have had a number of years experience connected with wind tunnel testing or flight test analysis. The salary for this senior post will be of the order of £2,000 per annum with additional non-contributory pension and life assurance benefits.

Further details of the work of the Society's Technical Department and of the vacancies on its staff may be obtained from:

The Head of the Technical Department

ROYAL AERONAUTICAL SOCIETY

4 HAMILTON PLACE, LONDON W.1

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The Royal Aeronautical Society
The First Fifty Years

BY

J. LAURENCE PRITCHARD, C.B.E., Hon.F.R.Ae.S., Hon.F.I.A.S.

1869 - 1870

It was nearly a year after the holding of the Aeronautical Exhibition, before the next meeting of the Society was held on 20th May 1869.

Despite the fact that in the first three years of the Society's life much attention had been paid to heavier-than-air ideas, the Chairman, Glaisher, had lost none of his enthusiasm for balloons for certain purposes.

"They met that night under peculiar circumstances," he said, "there being in London at this time the largest balloon yet made."

Glaisher referred to Henri Giffard's captive balloon, capable of lifting twenty people at a time. In a calm it could be held captive at 2,000 ft., and was exhibited at Ashburnham Park. Giffard placed the balloon at the disposal of Glaisher for taking meteorological observations, and he made close on 30 ascents in it on behalf of the British Association, in whose transactions the results are reported.

Nevertheless the Members as a whole were not disturbed by balloons. Many were convinced that the coming of the aeroplane was only a matter of time. In the first paper read at the May meeting Captain Murray of the Royal Navy suggested that a fund should be raised to investigate the problem and offered £10 as an immediate contribution. "I have attempted the problem myself, but the result has been to convince me that it is a hopeless task for anyone not gifted with the very highest mathematical capacity to attack even the simplest cases of it."

Charles Brooke, a Fellow of the Royal Society, and a member of the Council, drew attention "to a fact that is lost sight of, that when velocity of an opposing surface has done its work upon the air, this has got to get out of the way, and that much depended upon the inclination of the surface."

Charles Brooke was one of the most brilliant members of the Council, to which he had been elected in 1868. A friend of Wenham, he took a first class degree in mathematics at Cambridge, and afterwards trained at St. Bartholomew's Hospital and became a Fellow of the Royal College of Surgeons. His interest lay largely in theoretical and practical physics, and he invented and improved recording apparatus of many kinds. His first published paper (1835) was on the motion of sound in space. He became President of the Meteorological and Microscopic Societies and was elected a Fellow of the Royal Society in 1847 for his work on self-recording instruments. He remained a member of Council until his death in 1879.

Thomas Moy, who had already distinguished himself in the Society's discussions, and had given one lecture, gave another at this May meeting on the power and surface required for flight, the thrust of an airscrew, and the flight of the albatross. He livened up the debates of the Society for many years. He lived in Cliffords Inn, in London, and had a small engineering shop not very far away in Farringdon Street. An Associate of the Institute of Naval Architects, he advertised in the *Annual Reports* of the Society as a "consulting engineer in aeronautical science, inventor and patentee of light steam boilers and engines for carriages, boats and aerial purposes."

Thomas Moy was to become one of the striking figures in the struggling history of the Society, and was not afraid of challenging any ideas put forward by others.

In his May 1869 lecture he showed curves which related the necessary horsepower against the pressure per square foot for flight. Moy was a practical visionary, but in the course of the years he lost a fortune helping others, as well as himself, to experiment in the search for the principles of flight.

E. W. Young, discussing Moy's paper, stated that during the previous summer he had carried out experiments to find the lift on an inclined surface in a wind, and finished by saying he thought it would be found that the mechanical flight by man would be effected without the necessity for such great speeds as some anticipated.

J. M. Kaufmann, an engineer, in his lecture "A few remarks upon Aerial Transcursion," after citing a number of his calculations, declared the aircraft he visualised would have "14 tons sustaining power." This, mark you, with flapping wings. James Glaisher from the Chair declared that he was now so old he could not believe in any aerial machine in action in the year till he saw it in action.

D. S. Brown, who was an active experimenter as well as a theorist, drew attention in his paper which followed, to the comparatively small amount of power required for take-off and climb. He ingeniously suggested that an experiment could be carried out by using a train as a moving test bed.

"A great deal is expected from this Society," he declared, "but I think we may complain of the little support we receive from the public . . . I have no hesitation in saying that if only a thousandth part of the money which has been worse than thrown away in horse racing, had been expended in aerial experiments, the problem would have been solved long ago."

Brown was the first member to suggest the use of aluminium in aviation. "I have by me here," he said, "some specimens of metallic foils; that of aluminium is so light and strong that a tubular boiler, or generating apparatus, would weigh so little—I fear to say how little, lest it should be thought incredible."

These aluminium specimens created a mild sensation and a far from mild disbelief in the claims

Brown made for them. Glaisher said, "Mr. Brown had referred to the very thing wanted—a light engine with very great power. This was wanted in the present state of, he was going to say, knowledge, but he would rather say want of knowledge."

Charles Brooke, from the Chair, drew attention to the extreme difficulty of working aluminium, while another engineer, Lewis Ulrick, violently attacked Brown's suggestion, calling his aluminium tin foil and saying he would never find a boiler maker in England to entertain making use of it. The great Wenham came to Brown's rescue by saying that an aluminium boiler had been made with the top and bottom screwed on, thus eliminating riveting, soldering or caulking, to which Ulrick and others had so strongly objected as being impossible with aluminium.

Mr. R. Sheward, described in the *Annual Report* as an engineer, was fairly howled down after he had described a method of lifting-yourself-up-by-your-bootlaces.

"Give us," declared H. F. Alexander, in the next lecture, "a motive power equal to steam, but generated from only a few pounds weight, and we shall at once have aerial machines on both the wing and the screw principle, when practical experience will soon decide which is the most suitable. Such a power man will yet have; such a power our scientific men may yet work out, even in our own way."

Alexander pointed out that the only practical method of lift in his day was by the use of hydrogen or coal gas; and the only practical power was that of the steam engine; while the only propelling apparatus was the airscrew. He suggested, therefore, that the balloon was the answer, *at that time*, "cigar, cylindrical or other more convenient shape," in other words, the airship.

Alexander suggested that by means of steam jets the whole problem of steering and control and forward motion of the airship could be solved.

The *Annual Report* for 1869 printed a translation of de Lucy's paper on the Flight of Birds and Insects. In the translation the word aviation is used for the first time in the *Reports* and there is an interesting note by the translator "The word aviation (*avis-agere*) is employed by the French to designate the system of aerial locomotion applied by man in imitation of the bird."

De Lucy made a good study of the conditions necessary for flight. He measured the weights of flying insects and birds and their wing area and enunciated that the area of the wings of flying creatures varies in an inverse ratio of their weights. He made a very large number of measurements and published a table of surfaces of birds and insects, assuming a fixed weight for comparative purposes.

De Lucy then considered the horsepower of insects and birds and quotes Borelli as having calculated that a bird weighing a kilogramme must be able to exert 133 h.p., and a goose weighing 3 kilogrammes exerts 400 h.p.! Colomb, famous for his researches into electricity and magnetism, calculated that the wing area required to support a man was 287,000 square yards!

De Lucy's account of his observations and experiments and his analysis are worth reading to this day, not only because of some of the conclusions he draws, but as a revelation of the outlook of the good research worker of his time on one of the greater problems of the day.

The concluding words of his paper are worth quoting.

"Science is ripe, industry is ready, everybody is in expectation; the hour of aerial locomotion will soon arrive . . . . it will be, without contradiction, one of its most glorious conquests, and one of the most fruitful for the future of mankind."

The year ended with a total of 104 members, of whom 71 were noted by Brearey as having paid their annual subscription. There was a balance of £6 11s. 0d. to carry forward, against a deficit of £46 13s. 0d. in the Exhibition year. The total income for the year was £90 3s. 0d., an indication that the Society was being run on a minimum of expenditure and a maximum of enthusiasm.

The year 1870 is a notable one in the Society's history. At the May meeting of Council Sir William Fairbairn drew attention to the absence of data giving the "reactions and lifting forces" on airscrews, and expressed his opinion that experiments would not be difficult to make, to obtain the necessary data.

At this meeting James Glaisher stated that he had been trying to obtain data concerning the forces on plane surfaces by using two anemometers at the same time, so as to be sure of comparative results. He reported that he had found an indication of increased lift with size of surface, and that equal surfaces, of varying shapes, gave different results. To the modern aerodynamic mind these conclusions may appear child-like and bland, as Bret Harte said of a very different experiment, but it must be remembered that there was no obvious reason, in the absence of practical test, why one square foot of one surface should not give as much lift and drag as another similar square foot.

Out of the discussion the Council agreed that an experimental fund should be raised for the construction of a suitable and well-finished anemometer "having the means of instantly setting various plane surfaces at any required angle and capable of registering both horizontal and vertical forces simultaneously for all degrees of inclination. The results to be published for the benefit of the Society."

At the June meeting of the Council the suggestion was followed up more specifically and it was "Resolved that an experimental fund be formed with a view in the first instance to ascertain the fundamental relation between velocity and pressure on surfaces of different areas and inclinations, and that a committee be formed to co-operate with the Council to carry out the experiments." In July the experimental committee was appointed. It included two Fellows of the Royal Society, Charles Brooke and James Glaisher, and four engineers of standing, F. H. Wenham, E. W. Young, D. S. Brown and Le Feuvre.

Le Feuvre was a past President of the Society of Engineers, and D. S. Brown had not only lectured before the Society but had taken out several aeronautical patents.

F. W. Young, a member of the Society and of the Institution of Civil Engineers, was a Civil Servant and went into the Colonial Service in the Harbours and Rivers Department. He had not only suggested the Society's early experiments, but had carried out some experiments himself.

In the Concluding Remarks at the end of the *Annual Report* further attention was drawn to what the Society was trying to do in this fundamental aerodynamic research.

"The Aeronautical Society has been endeavouring for some time to inaugurate a systematic series of

experiments on the connection between the pressure and velocity of air, and it is believed that these will afford the only data on which a true science of aeronautics can be founded.

"For this purpose an instrument has been designed by Mr. F. H. Wenham and approved by the Experimental Committee, which it is intended to submit to the action of a fan not less than 30 in. diameter, capable of delivering about 3,000 cubic feet of air per minute. A clear space of 15 ft. or more in front of the fan will allow room for a square wooden trunk to guide the blast, ascertain its velocity, and insert the anemometer. Mr. John Browning, F.R.A.S., will undertake the construction of the instrument, and Sir William Fairbairn, F.R.S. will afford all the aid in his power for its submission to the required test."

These were the first experiments ever to be made in a primitive form of wind tunnel. The tunnel was ten feet in length and eighteen inches square. "The plane to be acted upon," to quote the fuller description of the 1871 *Annual Report*, "was fixed to the long end of a horizontal arm, which vibrated like the beam of a balance, and bore upon its shorter end a sliding counterweight, so as to balance the weight of any plane which might be fixed at the opposite extremity. The horizontal or direct pressure was read off by a spring steelyard, which was connected to the end of a lever from a vertical spindle close to the base of the machine. The vertical or raising force due to the various inclinations was read off by an upright spring steelyard."

When James Glaisher took the Chair at the Annual Meeting on 3rd June, 1870 in the Theatre of the Society of Arts, he said

"I cannot say we have made much progress during the past year, but that was not to be wondered at when they had no experimental data and when practical men were so much engaged as to have little time for making the experiments that were so much required for the development of aeronautical science."

Walter Clare read the first paper, entitled "A Glance at Aeronautical Science." His paper aimed at saying to his audience, "Where are we now and where do we go to next?" "Onwards and upwards," he declared, "should be the Society's motto". It is not too late to adopt it.

Clare analysed the existing methods of approach towards solving the problem of flight, beginning with the prevalent idea that the study of bird flight would enable men to fly.

He made a remark which should be in every aeronautical designer's office. "As we can only hope to build up future successes on past failures, I think all failures ought to be discussed and analyzed."

Clare proposed several methods of full-scale experiments in safety, and ended his lecture, "I have merely tried to show you how little we know on the subject of flight, being well assured that the first and most important step towards knowledge is a thorough conviction of ignorance."

Following an interesting discussion Glaisher revealed that the Council that day had passed a resolution to carry out some experiments on the pressures on flat surfaces, and unanimous approval was promptly given for the Council's proposals. Stewart Harrison made the ingenious suggestion that an experimenter should ride a velocipede along a given track, using fixed wings, and pass over a weighing machine, which would record the amount of any lift due to pressure on the planes.

The next paper was by Dr. Smyth entitled "An instrument to measure the relative Pressure and Velocity of the Wind," and in it he described a new method of measuring the velocity of the wind dependent upon the action of two anemometers separated at a given distance apart to record the time a gust travelled between them and its force.

The second general meeting of members for the year was held on 13th July.

Ever since the foundation of the Society there had been controversy as to whether the flapping wing or the airscrew was the more efficient for propulsion in flight, and the question cropped up again at this meeting. Charles Brooke declared from experience of reciprocating and continuous rotary motions that he was in favour of the latter.

Glaisher, who did so much to guide the Society in the way it should go and to encourage it in its early years, again put his finger on the fundamental difficulty facing them.

"We are in total ignorance of the connection between velocity and pressure in an elastic medium like air. I am very desirous that experiment should be made to supply this want. It is of no use to expect mathematicians or mechanicians to investigate this connection until they are supplied with the necessary data, such as alone experiment could afford . . . . I particularly wish the attention of the Society to be directed to it. There are great difficulties in the way, but I have long excluded the word impossible from my vocabulary."

Major J. Scott Phillips described at this meeting an aeroplane which had one merit at least, a wheeled undercarriage. His engine was founded entirely on Hero's steam jet reaction principle, and Moy added his usual quota of damning criticism, followed by the Chairman of the meeting in the same vein.

I quote from the *Annual Report*.

"Major Phillips gathered up his papers and shortly afterwards left the room, declaring that they did not understand his invention and would not understand it."

That was the last heard of the gallant major, who resigned from the Society when his next annual subscription became due.

F. D. Artingstall, the ingenious and persevering mechanic of Manchester, who was unable to attend the meetings in London, sent in a long communication in which he discussed the power required when flight was in progress. Unfortunately, no discussion arose on the communication, although it was one of those papers which greatly merited it. Artingstall was trying to show from first principles that the power for horizontal flight was considerably less than many people believed to be the case.

A non-member, F. Senecal (who joined the following year) described an apparatus he had made to show the movements of the wings of birds and insects, as the wing tips traced their movements over black paper. The apparatus not only traced the movements, but indicated the speed, and the degree of flexibility of the wings.

Senecal gave a detailed description of his long series of experiments in the true tradition of research, and even the critical Moy was constrained to declare that the author was deserving of great credit for his ingenuity. Senecal was a watchmaker, and showed at

the meeting a number of small models which he had made to simulate the flight of insects.

In the *Annual Report* for 1870 was published a translation of an important paper by the Dutchman E. P. Harting on the relative sizes of the wings and pectoral muscles of flying insects, birds and animals. Harting drew special attention to the square/cube law, and pointed out that no direct comparison could be obtained between the areas and lengths of wings and weights of flying animals, birds and insects.

The year saw, in the autumn, the siege of Paris, and the Concluding Remarks of the year begin with the words, "The most remarkable events of last year in relation to aeronautics consist in the unprecedented practical employment of balloons for carrying mails and passengers from besieged fortresses and over hostile territories."

It could not be denied by the honest advocates of the heavier-than-air machine that the balloon had definitely stolen a sky march on them. Glaisher, in his *Travels in the Air*, stated that over 60 balloons had left Paris, carrying some ten tons of mail, while, according to M. de Fonvielle, one of the earliest honorary members of the Society, who had escaped from the siege of Paris, some 20 tons of freight were also carried. Glaisher noted that the German guns could reach a height of 3,000 feet, so that the balloons were forced to fly well above that altitude.

These comments at the end of the *Annual Report* were largely prepared by Wenham, who played such a great part in the Society, behind the scenes as well as at its meetings.

The income for the year was £74 9s. 0d. and expenses £72 9s. 9d. leaving £1 19s. 3d. to start 1871. The membership was 95 of whom only 43 had paid their subscriptions, one, Sir Charles Wright a member of Council, being four years in arrears.

So ended the first five years of the Society's existence. They had been, for the little band which had struggled through them all, exciting, nonsensical, interesting, but above all hopeful. Those five years of the imaginative, enthusiastic few who believed in the things they would not live to see . . . Faith, they knew, could move mountains, or at least, fly over them.

But they had been more than hopeful. Wenham had laid down first principles, and he and many others, had declared that along the paths of organised research must ultimately be found the secret of success. The end of the first five years had seen the first steps being taken along aerodynamic paths.

It must be conceded, whatever other criticisms may be made, that much of the sustained interest and success of those early years is due to Brearey. He was 50 years of age when he read a paper to the Council meeting of 28th February 1866, an age when many men are looking forward to the not too distant future of retirement. For Brearey it was the beginning of a new life, a new interest, lasting for the next thirty years, to provide him with a niche in the aeronautical temple of fame.

His father, Christopher Brearey, was the Coroner for Scarborough. He died when Fred Brearey was a boy and Fred was brought up by his eldest brother. Although Christopher Brearey was a friend of Sir George Cayley, there is no record that the future aeronautically energetic son showed any interest in flying until middle age. Nor did any of his brothers, for one went to Brazil and became a planter there, another settled as a doctor in Scarborough after an adventurous career in the Spanish army, and the third brother rose to be a captain in the Merchant Service.

The Breareys, indeed, were of a fighting and adventurous stock. An ancestor was killed in 1644 while defending the walls of the city of York in the Royalist cause. Brearey's grandfather was a captain in the 4th, of King's Own, and Lord of the Manor of Middlethorpe, adjoining the grounds of the Archbishopric of York. Tradition has it that the Manor was granted to an ancestor for his defence of Ryland Abbey. It is certain that the Breareys lived there for over 200 years. Two members of the family became Lord Mayors of York, one was Archdeacon of East Riding, and another, Canon Samuel Brearey, has a monument in York Minster. Brearey's father fought at the Battle of Waterloo.

When Brearey came to London and what he did until he became the Honorary Secretary of the Society, have not been recorded. He left no record himself and none has been found in the Society's archives. Long years after his death in 1896, a great-nephew told me, "He was a rather fierce-looking old gentleman, something like an eagle. I can remember him standing on a pedestal flapping two big wings up and down. I knew he wrote articles on the pectoral muscles of pigeons."

The pedestal was one of those music stools which turned round on a large wooden screw. Brearey himself recorded in later years that it was one of his experiments to demonstrate the force exerted by a bird's wing, sufficiently great in this instance to turn round the music stool on which he stood, flapping his big wings.

To found a Society in order to discuss the secret of flying was an adventure on the grand scale in the middle of the nineteenth century. Indeed, but for the fact that the British Association had been carrying out research work in the air with balloons, under the direction of James Glaisher, anything to do with trying to fly might easily have involved a charge of lunacy.

Brearey was told by his sister that she had witnessed, with their father, some of Sir George Cayley's early experiments. It was the first time he had heard of them. He always admitted that he had little scientific knowledge and was not very skilled with his hands, but Cayley's writings fired him with the possibility of "Aerial Navigation."

Brearey soon began to absorb some of the inevitable jargon of aeronautics and to begin to get some ideas of his own. The announcement that an aeronautical society had been formed brought him letters from all parts of the world, letters containing ideas and appealing for help generally. Single-handed he answered all the correspondence and threw himself into the work which the Society entailed. He wrote articles as well as letters to the magazines and newspapers of the time, and in later years toured the country giving lectures, and advertising the Society and its work with astonishing vigour and enthusiasm, when most men of his age were ready to sit back and live a life of contemplative leisure.

He must have felt that the first five years were encouraging enough for another five to follow, and another and another and many others.

AUTHORITIES: *Annual Reports*, 1869-70; Minutes of Council 1869-70; Brearey's notebook of expenses; *Aeronautical Journal*, January 1897; MSS. of Brearey's memoir; *Dictionary of National Biography; Mechanics Magazine*, 1869-70.

TECHNICAL NOTES

Lower Bounds for Sonic Bangs

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LOWER BOUNDS for the intensity of the sonic bang of a slender aircraft configuration with various constraints are given in this note which is a condensed version of Ref. 1. Although these lower bounds cannot be achieved in practice the method of obtaining them demonstrates how low values can be obtained. Special emphasis is given to a possible supersonic transport.

NOTATION

a	lifting length (ft.)
F	Whitham's F-function
h	height of aircraft (ft.)
l	length of aircraft (ft.)
L	total lift (lb.)
$L(y)$	chordwise lift per unit length
M	Mach number
Δp	pressure jump across shock wave (lb./ft.^{2})
p_a	air pressure at altitude of aircraft (lb./ft.^{2})
p_g	air pressure at ground level (lb./ft.^{2})
S	cross-sectional area distribution of aircraft (sq. ft.)
V	volume (cu. ft.) or aircraft speed (ft./sec.)
W	weight of aircraft (lb.)
y_0	zero of the Whitham F-function
β	$\sqrt{(M^2-1)}$
γ	ratio of specific heats
ρ	density

INTRODUCTION

The sonic bangs caused by supersonic aircraft can be a nuisance, and since it is known that the level of noise of these bangs is on the border-line of the acceptable value, it seems important to examine ways of reducing them at the aircraft design stage.

In this note values for the lower bounds of the intensity of the sonic bang are given for the case of a slender aircraft configuration flying straight and level and at constant speed. Although these lower bounds cannot be achieved in practice the method of obtaining them demonstrates how low values can be obtained.

The pressure jump across the front shock directly beneath the aircraft is given in Ref. 2 and is

$$\frac{\Delta p}{\sqrt{(p_a p_g)}} = \frac{2^{1/4}\gamma\,\beta^{1/4}}{(\gamma+1)^{1/2}h^{3/4}}\left[\int_0^{y_0} F(y)\,dy\right]^{1/2}$$

with

$$F(y) = \frac{1}{2\pi}\int_0^{y} \frac{S''(\eta)+\dfrac{\beta}{\rho V^2}L'(\eta)}{\sqrt{(y-\eta)}}\,d\eta$$

All quantities being defined in the list of symbols except y_0 which is some value of η such that

$$\int_0^{y_0} F(\eta)\,d\eta \text{ is a maximum and } F(y_0)=0.$$

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In the next section the pressure jump across the shock of a possible supersonic transport is given as an example against which the lower bounds obtained later can be compared.

SONIC BANG OF A POSSIBLE SUPERSONIC TRANSPORT

The following assumptions have been made about the aircraft geometry.

The area distribution is shown in Fig. 1 and is given by

$$S(x) = 1410\left(\frac{x}{l}\right)^2\left(1-\frac{x}{l}\right)$$

with $l=170$ ft. The apex of the lifting length is 40 ft. aft of the non-lifting nose so that a, the lifting length, is 130 ft.

$W=2{\cdot}0$ $\qquad h=55{,}000$ ft.
$M=300{,}000$ lb. $\qquad V=20{,}000$ cu. ft.

It has been assumed that the lift distribution is either linear or elliptic in shape. The F curves for volume, lift, volume + lift are given respectively in Figs. 2, 3 and 4. The corresponding values for the free air pressure jumps are for the linear loading

0·556; 0·929; 0·784; lb./ft.^{2}

The corresponding values for the elliptic loading are

0·556; 0·798; 0·888 lb./ft.^{2}

It will be noted that although the pressure jump due to lift alone of the elliptic distribution is less than that of the linear distribution the reverse is true when the total pressure jump is considered.

It is therefore necessary in any optimisation studies of the sonic bang to consider the lift and volume combined. However in the next section the lower bound for the sonic bang due to lift is obtained since this illustrates the techniques involved.

LOWER BOUND FOR SONIC BANG DUE TO LIFT

In order that the intensity of the sonic bang of an aircraft flying steadily at a given height and Mach

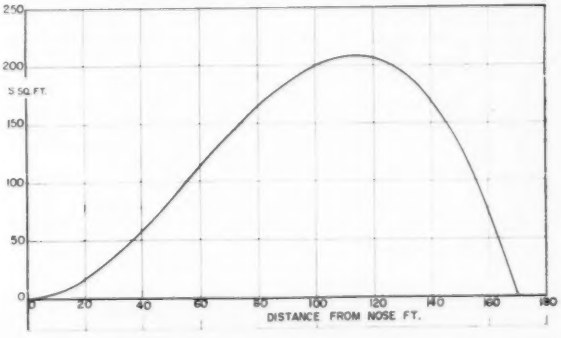
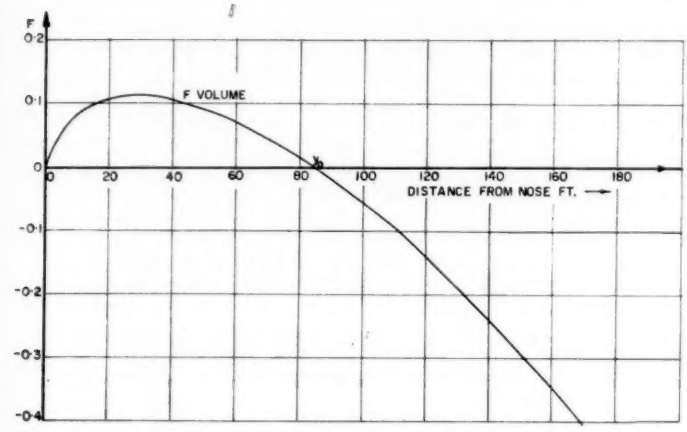


FIGURE 1. Area distribution for possible supersonic transport. Volume = 20,000 cu. ft.



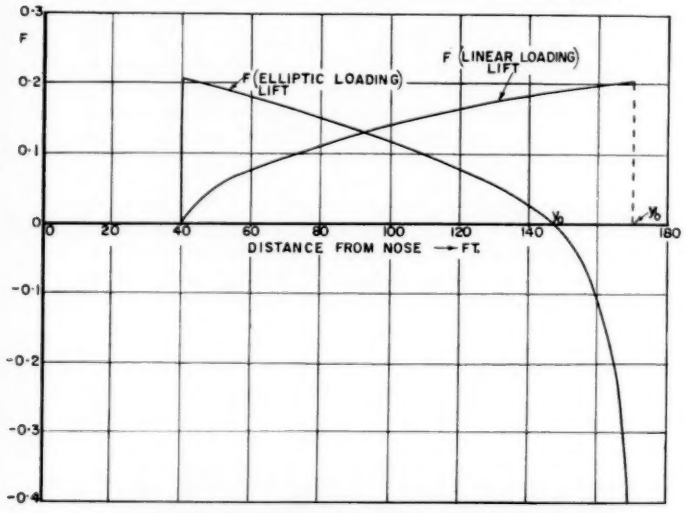


FIGURE 3. F functions due to lift for given area distributions. $M=2{\cdot}0$. $h=55{,}000$ ft.

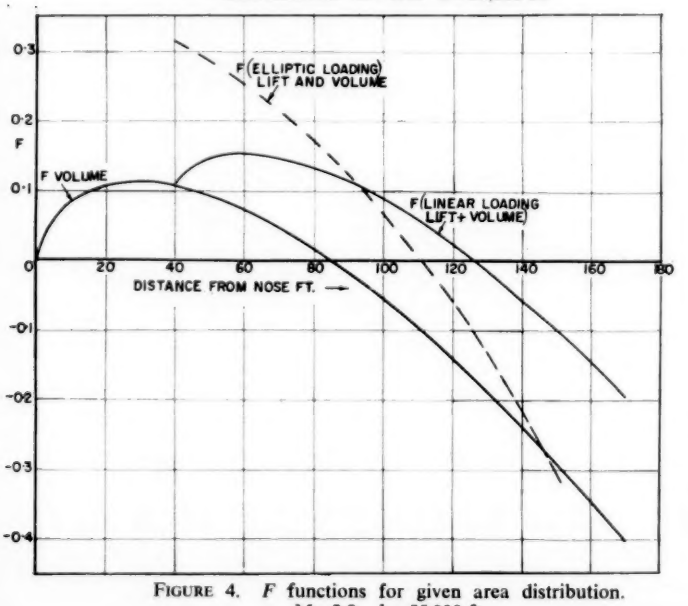


FIGURE 4. F functions for given area distribution. $M=2{\cdot}0$. $h=55{,}000$ ft.

FIGURE 2. F function due to volume for given area distribution. $M=2{\cdot}0$. $h=55{,}000$ ft.

number should be a minimum it is necessary to determine a minimum of

$$\int_0^{y_0} F(y)\,dy$$

under certain constraints. In this instance the total lift and lifting length are given, and where

$$F(y)=\frac{\beta}{2\pi\rho V^2}\int_0^{y}\frac{L'(\eta)}{\sqrt{(y-\eta)}}\,d\eta.$$

Now the above expression is an Abel integral equation, so that provided $F'(y)$ is continuous the loading distribution is given by

$$\frac{L'(y)}{\rho V^2}=\frac{2}{\beta}\frac{d}{dy}\int_0^{y}\frac{F(\eta)\,d\eta}{\sqrt{(y-\eta)}}.$$

Integrating the above expressions and since $L(0)=0$ it follows that

$$\frac{L(y)}{\rho V^2}=\frac{2}{\beta}\int_0^{y}\frac{F(\eta)}{\sqrt{(y-\eta)}}\,d\eta.$$

If L is the total lift,

$$\frac{L}{\rho V^2}=\int_0^{a}\frac{L(y)}{\rho V^2}dy=\frac{2}{\beta}\int_0^{a}dy\int_0^{y}\frac{F(\eta)}{\sqrt{(y-\eta)}}\,d\eta$$

which on changing the order of integration gives

$$\frac{L}{\rho V^2}=\frac{4}{\beta}\int_0^{a}F(\eta)\sqrt{(a-\eta)}\,d\eta.$$

It is this expression which gives the key to the minimisation problem.

It will be noted from the above expression that the F curve is more efficient in producing lift if it is located nearer the apex of the wing than the trailing edge. With this in mind it can be demonstrated that if the F curve is anywhere negative in the range 0 to a the value of $\int_0^{y_0}F(\eta)\,d\eta$ can always be reduced for given positive value of $\int_0^{a}F(\eta)\sqrt{(a-\eta)}\,d\eta$.

This therefore demonstrates that for low values of the sonic bang for given lift the form of the F curve should be as shown in Fig. 5. In the limit therefore the lower bound for the sonic bang of a thin wing at given lift is such that the F curve is zero except at the origin and is such that

$$\frac{L}{\rho V^2}=\frac{4}{\beta}\sqrt{a}\int_0^{a}F(\eta)\,d\eta.$$

The resulting value for the lower bound is therefore

$$\int_0^a F(\eta)\,d\eta = \frac{\beta}{4\sqrt{a}}\left(\frac{L}{\rho V^2}\right).$$

The expression for the chordwise loading in the limit is

$$\frac{L(y)}{\rho V^2} = \frac{1}{2\sqrt{a}}\left(\frac{L}{\rho V^2}\right)\frac{1}{\sqrt{y}}$$

except near the origin.

The chordwise loading for the F curve given in Fig. 5 is shown in Fig. 6, together with the curve for the lower bound. The ratio of the values for

$$\int_0^{y_0} F(y)\,dy \text{ is } 1{\cdot}011.$$

The ratio of the pressure jumps of a wing with linear loading to that of the lower bound is

$$\frac{\Delta p_{\text{LINEAR}}}{\Delta p_{\text{MIN.}}} = \frac{4}{\sqrt{(3\pi)}} = 1{\cdot}303.$$

The similar ratio for elliptic distribution is

$$\frac{\Delta p_{\text{ELLIPTIC}}}{\Delta p_{\text{MIN.}}} = 1{\cdot}120.$$

LOWER BOUND OF A SONIC BANG OF A SUPERSONIC AIRCRAFT WHEN ITS CROSS-SECTIONAL AREA IS GIVEN

Suppose that the design of the aircraft is frozen except that the wing may be cambered and twisted in order to change the chordwise load distribution. Suppose also that the area distribution is as given in Fig. 1 with the resulting F curve as in Fig. 2.

It will be noted from this F curve for volume that there is a negative region at the rear of the distribution. Now if the F function for lift is the mirror image of this negative region then this amount of lift is being carried without any increase in the pressure jump due to volume. This conclusion was also derived in Ref. 3.

The F function for lift should therefore be chosen such that over this rear region it is the mirror image of the negative F function for volume. If the resulting lift from the F function is greater than the weight of the aircraft then it is possible to obtain a total sonic bang intensity which is smaller than that due to volume alone, since this excess lift can be cancelled by taking all the F function for lift to be negative upstream of the zero at y_0. If on the other hand the resulting lift is less than that required, it follows from the previous section that it pays to concentrate this extra positive F function near the apex of the wing.

Returning to the example, the lift corresponding to the image of the F function due to volume aft of its zero is 185,000 lb. The excess lift which is required is 115,000 lb.

The resulting value for the lower bound for the sonic bang is 0·709 lb./ft.², which compares with the values of 0·784 lb./ft.² for the linear chordwise loading quoted earlier.

MINIMUM SONIC BANG DUE TO VOLUME

In this case the expression relating the F function to the cross-sectional area distribution is given by

$$F(y) = \frac{1}{2\pi}\int_0^y \frac{S''(\eta)}{\sqrt{(y-\eta)}}\,d\eta.$$

Inversion of this followed by integration gives

$$S'(y) = 2\int_0^y \frac{F(\eta)\,d\eta}{\sqrt{(y-\eta)}}$$

since $S'(0)=0$.

It follows that in the same way as the lift was obtained

$$S(y) - S(0) = 4\int_0^y F(\eta)\sqrt{(y-\eta)}\,d\eta$$

or the special case

$$S(l) - S(0) = 4\int_0^l F(\eta)\sqrt{(l-\eta)}\,d\eta.$$

Integrating once more, the volume is

$$V = lS(0) + \frac{8}{3}\int_0^l F(\eta)(l-\eta)^{3/2}\,d\eta.$$

Some general comments can be made before any special cases are considered.

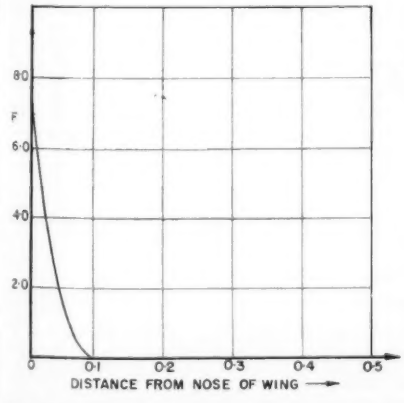


FIGURE 5. F function due to lift for low value of sonic bang for given lift.

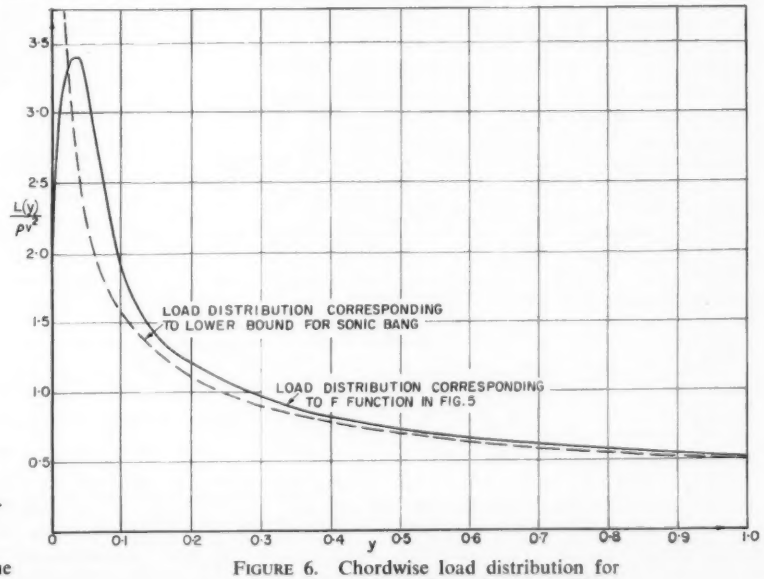


FIGURE 6. Chordwise load distribution for low value of sonic bang for given lift.

The F curve is more inefficient in "producing" volume near the base of the body than it was in producing lift for the lifting case. So that subject to further restrictions it pays to concentrate the F function due to volume near the nose of the body.

For bodies which are closed $F(\eta)$ must have a negative area in the range 0 to l. It can also be seen from the expression relating the slope of the cross-sectional area distribution to the F function that the F function must change sign upstream of the position of maximum cross-sectional area.

Consider first the case of a slender body of given length, closed at front and with given area at the base. The expression for the base area in terms of the F function is similar to that one for the lift of a thin wing so that the arguments used for the lifting wing can also be used for this case.

The lower bound value for $\int_0^{y_0} F(\eta)\,d\eta$ is therefore $S(l)/4\sqrt{l}$. The distribution of $S(x)$ for this lower bound is $\sqrt{x}/\sqrt{l}$ except near the origin.

Next consider the case of a closed body of given length and volume. From the general comments above it is seen that the F function should be chosen such that the positive area is concentrated at the nose and the negative region at the base and is such that

$$\int_0^l F(\eta)\,\sqrt{(l-\eta)}\,d\eta \text{ is zero.}$$

It follows from the relationship between volume and the F function that this negative region is contributing no volume and hence the lower bound for sonic bang is obtained with

$$\int_0^{y_0} F(\eta)\,d\eta = \frac{3}{8}\frac{V}{l^{3/2}}$$

The resulting ratios for the pressure jumps of a parabolic distribution and the area distribution given for a supersonic transport are

$$\frac{\Delta p_{\text{PARABOLIC}}}{\Delta p_{\text{MIN.}}} = 1{\cdot}515$$

$$\frac{\Delta p_{\text{TRANSPORT}}}{\Delta p_{\text{MIN.}}} = 1{\cdot}385.$$

LOWER BOUND FOR SONIC BANG DUE TO VOLUME PLUS LIFT

Here we will consider the case of an aircraft of given length, lift and volume.

From the previous discussions, part of the F function due to lift should be taken as the mirror image of the negative F function due to volume.

The F function for volume is taken as above. The negative area of the curve $F\sqrt{(l-\eta)}$ is then $3/8\ V/l$.

The lift due to the reflection of the negative region of the volume curve is therefore

$$\frac{L_R}{\rho V^2} = \frac{4}{\beta}\left(\frac{3}{8}\frac{V}{l}\right)$$

The extra lift which is required is

$$\frac{L}{\rho V^2} - \frac{4}{\beta}\left(\frac{3}{8}\frac{V}{l}\right)$$

The extra F function which produces this excess lift should be concentrated at the apex of the lifting length, and the resulting value of the integral of the F curve for this excess lift is

$$\int_0^{y_0} F(\eta)\,d\eta = \frac{\beta}{4\sqrt{a}}\left(\frac{L}{\rho V^2} - \frac{4}{\beta}\frac{3}{8}\frac{V}{l}\right).$$

The required value of the lower bound is the sum of that for volume alone plus the above expression since the value of y_0 is unchanged. That is

$$\int_0^{y_0} F(\eta)\,d\eta = \frac{\beta}{4\sqrt{a}}\frac{L}{\rho V^2} + \frac{3}{8}\frac{V}{l}\left(\frac{1}{\sqrt{l}} - \frac{1}{\sqrt{a}}\right).$$

The integral of the F function which gives the value of the lower bound for sonic bang is therefore the sum of that for volume alone plus that for excess lift. In the special case of the lifting length being the same as that of the overall length then the lower bound becomes the same as that for lift alone. The resulting ratios for the pressure jumps for the example quoted earlier are

$$\frac{\Delta p_{\text{LINEAR}}}{\Delta p_{\text{MIN.}}} = 1{\cdot}134$$

and

$$\frac{\Delta p_{\text{ELLIPTIC}}}{\Delta p_{\text{MIN.}}} = 1{\cdot}283.$$

CONCLUSION

Values of the lower bounds for the sonic bang intensity have been given for various conditions. It has been shown that for a possible supersonic transport configuration the intensity of the sonic bang can be reduced by amounts which may not be negligible if these are in fact on the borderline of the acceptable limit. However there are practical considerations which will limit the extent to which these gains could be achieved in practice.

ACKNOWLEDGMENT

The author wishes to thank English Electric Aviation Ltd. for permission to publish this work.

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Reconnaissance Orbits Normal to the Ecliptic Plane

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THE ecliptic plane is the plane of the orbit of the Earth round the Sun. In a previous note[1] the velocity requirements were examined for conventional rocket vehicles to enter reconnaissance orbits around the Sun in this plane.

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Departure from the ecliptic plane obviously involves an increase in the velocity requirement. To some extent, all interplanetry voyages necessitate such motion, as the planets lie in planes inclined to the ecliptic. In this note, the extreme case of entry into orbits normal to the ecliptic will be considered. Such orbits are likely to be of great interest

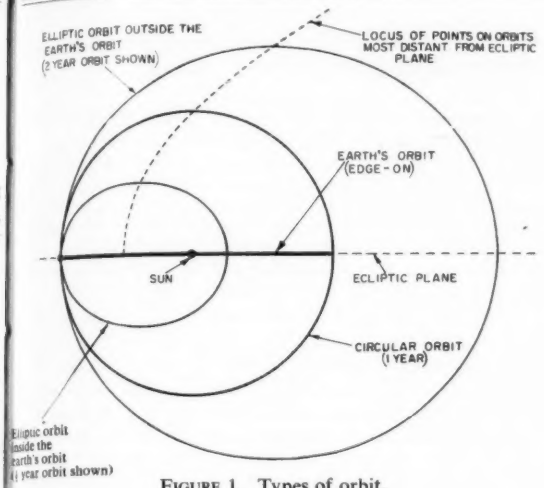

ELLIPTIC ORBIT OUTSIDE THE EARTH'S ORBIT (2 YEAR ORBIT SHOWN)
LOCUS OF POINTS ON ORBITS MOST DISTANT FROM ECLIPTIC PLANE
EARTH'S ORBIT (EDGE-ON)
SUN
ECLIPTIC PLANE
CIRCULAR ORBIT (1 YEAR)
Elliptic orbit inside the earth's orbit (½ year orbit shown)

FIGURE 1. Types of orbit.

in connection with solar research, as solar phenomena normal to the ecliptic appear to be different, at least in intensity, from those in the ecliptic. The solar equator lies at an inclination of about 7° to the ecliptic, so the solar poles lie roughly in planes normal to it. This will be precisely so on two launching opportunities each year.

The assumption used in the earlier note that conventional rocket systems will be used is here repeated. The most economic orbits from the point of view of minimum energy requirement again turn out to be ellipses (Fig. 1). At propellant cut-off the vehicle must have acquired a velocity such that, when it has substantially escaped from the Earth's gravitational field, the Earth's velocity round the Sun, which it possesses at launching, is reduced to zero, and it has a velocity normal to the ecliptic sufficient for it to enter the desired reconnaissance orbit.

The velocity requirements at cut-off are shown in Fig. 2. For the simplest case of a direct fall to the Sun, the requirement is 19·8 miles/sec., and at this point the curve joins on to the curve of Fig. 2 of Ref. 1. For all other orbits, the velocity requirement increases with increasing size of orbit. This result contrasts with the result of the calculations for orbits in the ecliptic plane, for which the degree of departure from the Earth's orbit is a measure of the velocity requirement increase.

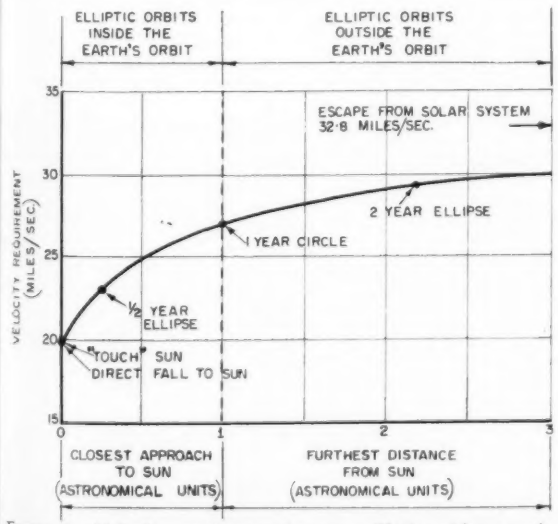


FIGURE 2. Velocity requirement to enter elliptic orbit normal to the ecliptic plane.

For the extreme upper case of escape from the solar system along a parabolic path, the velocity requirement is 32·8 miles/sec. This is an appreciable increase on the figure of 10·3 miles/sec. for escape in the ecliptic plane.

It is not possible in these early days of astronautical endeavour to envisage applications for probes in this category travelling outside the Earth's orbit, quite apart from the restrictions imposed by the very high performance requirements. Attention will therefore be concentrated on orbits within the Earth's orbit.

Undoubtedly the prime purpose of such probes will be to find out more about conditions in the extremely tenuous atmosphere that we misleadingly term "space." Inside the Earth's orbit this atmosphere appears to be largely dominated by, and in fact largely produced by, the Sun. Solar phenomena are not, as is well known, uniformly distributed over the Sun's "surface," and as soon as possible it will be desirable to fly over the solar poles. The closest possible approach will be by a probe that "touches" the Sun, assuming, of course, that technology will have advanced sufficiently for the vehicle to resist the very high radiation intensity incident upon it during a close pass.

The velocity requirement for this is only slightly higher than that for the direct fall, by as little as 1/20 mile/sec. It is therefore important to realise that, once the direct fall becomes practicable, the vitally important close polar flight becomes almost immediately practicable too.

Two other orbits of particular interest are indicated in the illustrations. The half-year ellipse permits an approach to about 0·4 of an Astronomical Unit above each pole in turn during each journey round the Sun, and the probe thus has two looks at each pole in one year's absence from Earth, after which it will return to the Earth's vicinity. In addition, of course, it will pass as close as 0·26 of an Astronomical Unit to the Sun in the ecliptic plane during each period of a half year. The velocity requirement for this orbit is 23·1 miles/sec., compared with 9·6 miles/sec. in the ecliptic plane.

The second orbit of particular interest is the circular orbit of one year's duration. This is a reproduction of the Earth's orbit normal to the ecliptic. The velocity requirement is certainly high, at 27·1 miles/sec., but the orbit might well find favour in the future for the following reasons. The probe traces out a circle at a constant distance of one Astronomical Unit from the Sun, and is above one of the solar poles three months after launching. Transmission of data might be attempted at that time over a distance of $\sqrt{2}$ Astronomical Units, or data might be stored for transmission six months after launching during the close pass of the probe to the Earth. It is clear that the coming together of probe and Earth every six months is a useful feature of the orbit. No special provision need be made for changes in environmental temperature, apart from the launch phase, for the constant distance from the Sun will ensure little variation in operating temperatures.

While it is evident that flights departing from the ecliptic plane to an appreciable extent will only become practicable with the advent of vehicles of substantially advanced performance, the most valuable orbits to be flown, those passing close to the solar poles, will be among the first to be realisable.

REFERENCE

1. GREENWOOD, S. W. (1960). Solar Probes. *Journal of the Royal Aeronautical Society*, February 1960.

The Third Branches Conference in the Provinces was at the invitation of the Preston Branch.

What began two years ago as an experiment may now be considered to be an established tradition—the idea is a success. But this third "away summit" began a tradition which it would be worthy to repeat if it were not so chronologically improbable, being that the Conference should be the first formal appearance of the incoming President of the Royal Aeronautical Society.

It was so on this occasion, and a warm welcome was given to Air Marshal Sir Owen Jones. Dr. Ballantyne was in the chair as Chairman of the Branches Committee, with Miss Barbara Croad as Secretary. While the only lady attending the Conference itself, several Branch Chairmen and Secretaries brought their ladies to Preston for the Reception of the previous (Friday) evening, and it is here that our story should properly begin.

The English Electric Company, Warton, were hosts to the reception, which must have been attended by some hundred or more persons, with many local members to look after the visitors. Forty-three attended the Conference, and as these represented every Branch in the Kingdom, with the exception of three, it was a measure of the support given by the Branches.

The reception was splendidly arranged, with gastronomic and accompanying libations of the highest order, the centre piece of the cold table being the Society crest modelled in whatever artistic cooks model these things. A graceful touch. Later in the evening, visits were arranged to the Plastics Division, the Low Speed Wind Tunnel, Mechanical Test, Flight Simulator and Computors, to a flight hangar with Lightnings, and to two High Speed Wind Tunnels.

This annual visit to a Branch includes an opportunity to view something of another aircraft organisation, and if not in the daily run of life, then is a powerful incentive to seek (or accept) office with a Branch. But for these Conferences, many Secretaries (and possibly Chairmen) would not have had the opportunity to view the Britannia, Beverley and Buccaneer, and now the Lightning.

Of value, too, is the chance for visiting, and local wives to appreciate what makes their husbands so wedded to aeronautics, and as time will also prove, to astronautics. Future Conferences offer future interests.

A film show was on the programme after these visits, but did not take place as (*a*) everyone had much too much to talk about and (*b*) the films did not arrive (owing to some security trouble). But a photograph (to be published next month) was taken of delegates the following morning in the finest of weather, which did its little to make this so successful and enjoyable a social and business occasion.

As to business, this was briskness itself with elected democracy modelling itself on question time in the House of Commons. This was the time to raise awkward questions and make outrageous proposals, and all to prove that this was no mere polite formality and also that there is some substance in the oft repeated saying that the strength of the Society is in its Branches.

Certainly, the lecture programme is to be strengthened at the Branches, and the Chairman proposed that Main Lectures at Branches should be offered to Brough, Glasgow, Isle of Wight, Manchester, Belfast and Yeovil for the Society lecture programme of 1961-1962.

A proposal, much approved, was that of the Chairman to hold a group of four lectures in one day at 4 Hamilton Place, so that this would be a worthwhile visit to London for Branch members. For various and peculiar reasons, Thursday was the chosen day of the week. Members felt that pre-prints of lectures would be more than usually valuable, which led to the wide subject of Society publications: the Chairman pointed out that some 64 lectures had been given to the Main Society, which would be an impossible burden on the JOURNAL if all were to be published.

Ideas were abroad on alternative forms and means of publication, but these were early days as yet and there were many problems to be overcome to meet the general desire for wider publication.

Reverting to dates, members might like to note that Council meetings are held on the last Thursday of the month and generally a Main Lecture on the second and last Thursday, so that these two Thursdays should, if possible, be free in Branch programmes.

"Subsidies" raised its head after a couple of dormant years, but the Chairman ruled that Branches abide by the original agreement to give the present arrangement a run of two years. This, however, applied more to the general than to the particular.

To the item on the agenda entitled "Branches Page" there appeared to be neither criticism nor comment—the Hon. Members of the Opposition lost an opportunity here, for while angry cries of "imperialist" and "capitalist" would certainly have been wide of the mark, your scribe would truthfully answer to being a "colonialist", if only by origin. Being uninhibited as colonialists are, your scribe attacked the Opposition for lack of interest, and failure to produce enough "copy" for this page.

The House then retired to luncheon, in the Majestic Hotel, St. Anne's-on-Sea, and the same venue as the Conference. Over liqueurs and cigars, the President thanked the local Branch, Mr. Williams (its Chairman), Mr. Foss (its Secretary), English Electric, and those Branch members who had entertained visitors in their own homes. Support from English Electric had been most generous, even to supplying an aircraft to fly some from London, and congratulations were offered to Mr. Foss and his Committee on their admirable organisation.

The Secretary of the Glasgow Branch must have also been gratified at so successful a Conference, for the suggestion to hold it away from London was originally his. The next Conference is to be held in London, subject to confirmation, on Saturday 18th November 1961.—G. W-W.

Graduates' and Students' Section

Russian Evening

On the evening of 10th May, Mr. Yarotski the General Representative of the Russian national airline, Aeroflot, gave us an account of his Company's operations.

The evening was divided into three parts. First, we had a general talk from Mr. Yarotski on the composition of the airline and this was followed by a question period. Finally, we saw four Russian films, three of them portraying types of air liners in service and the fourth, describing the Russian contribution to the International Geophysical Year.

Mr. Yarotski began by describing in general terms the responsibilities of Aeroflot as the state airline, and gave its principal missions as: (*i*) carrying passengers, (*ii*) carrying cargo, and (*iii*) carrying out agricultural and geological flights and ambulance flights. He stated that the Aeroflot territorial routes covered 7,000 miles, and then went on to describe in brief terms the types of aircraft in service. Of these, the Tu. 104 (named after Andrei Tupolev the Russian designer) is a 900 km/hr. aircraft powered by two large turbojet engines and capable of carrying 70 passengers over ranges of 4,000 km. This aircraft is used on international or foreign routes. The Tu.114 is an extremely large aircraft powered by four turboprop engines and capable of carrying 150 to 220 passengers over distances of up to 10,000 km. at speeds of 800 km./hr. It is used on internal routes. The Tu.124 is a smaller version of the Tu.104 and has turbofan engines, with a cruising speed of 1,000 km./hr. and provision for 40 to 60 passengers on routes of 1,500 km. length. Other aircraft mentioned were the Il.12, Il.18, Il.14, An.2, An.10, Yak.12, and the Mi. range of helicopters designed by Mikhail Mil. It was estimated that by 1965 the revenue of Aeroflot would have increased six-fold.

Aeroflot had calculated that there were always approximately 600,000 people on the move—by all forms of transport—in the U.S.S.R., and many of these were making use of slow forms of surface transport. So, it has become national policy to develop air transport to the extent that nearly all passengers will travel by Aeroflot, and this will mean a considerable saving of time and effort, and release more people for other tasks.

There was a slow start to the question period, but once under way it proved highly successful—at least, judging by the number of questions that Mr. Yarotski was requested to answer. It was felt that many of the answers were couched in very general terms, if not exactly evasive, and very few plain facts and figures were forthcoming. In reply to a question regarding Aeroflot air crew, Mr. Yarotski inferred that his airline did not make use of ex-Russian Air Force pilots but trained all their own air crew. He thought that a requirement for a supersonic air liner might have been made known to the Russian industry and it might appear in two years time. In reply to a question regarding the strength of the Aeroflot fleet, Mr. Yarotski said that it would be difficult for any one person to know as it was sub-divided into many sections, but we could be assured that there were many aircraft. Asked whether it was likely that Russia would ever order and operate Western aircraft, Mr. Yarotski thought that this was possible if aircraft of a high enough standard were available—and if there was some form of *quid pro quo*.

Films shown at the end were very interesting but more suitable for passenger consumption than for a technically-minded audience.

Finally, the Section was delighted that Mr. Yarotski was able to spare the time to talk to us and we would like to express our thanks for a most enjoyable evening, and hope that we shall see him again in the future.

Visit to the R.A.E. Farnborough

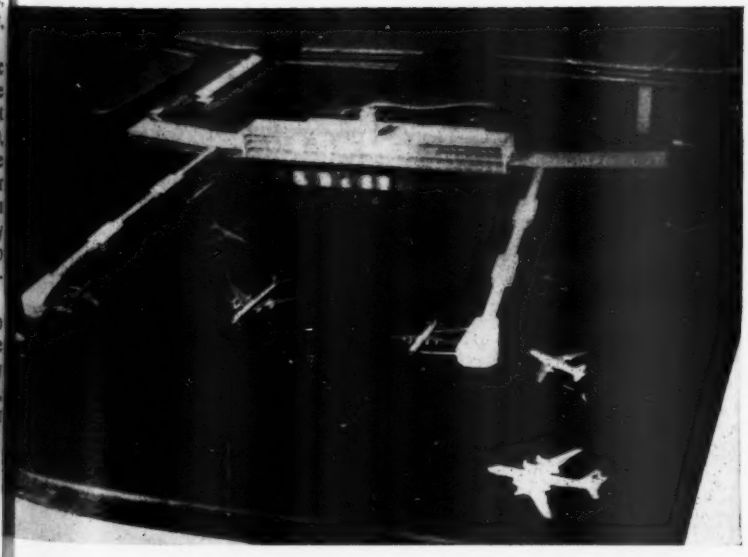
During May, a party of Graduate and Student members of the Society visited the Aerodynamics Department of the Royal Aircraft Establishment at Farnborough.

We were met at the gate by our guide and a bus waiting to take the party to the various sections of the Establishment which we were due to visit. Our attention was mainly confined to some of the many wind tunnels but our first stop was at the fatigue testing tank where the actual fatigue life of a pressurised aircraft is estimated.

Our attention was then turned to the wind tunnels of which we saw several of varying working-section sizes and speeds. None of us had actually been in a wind tunnel before so it was a novel experience to walk around in the working section of one tunnel and between the corner vanes of another which was undergoing repair. The combination of size and semi-darkness lent an air of sinister mystery to this apparatus —and altogether it was a most uncanny experience.

We were not able to go into the hypersonic tunnel because it was in use but we did go underneath it to see the power house which housed the driving motors and the storage tank for the cooling fluid which is used to conduct away the heat produced when the tunnel is run for several hours at a time. After tea and biscuits in one of the canteens, we were shown a further two tunnels, one supersonic and one intermittent. At this point we were joined by two more visitors who had spent their afternoon pursuing their own more specialised aerodynamic interests, and finally, we all went to see something of the work being done on Skylark. The test programme for this high-altitude vehicle was explained to us and we were also given some idea of its construction.

This concluded our visit—and we all agreed that it was the most interesting visit of all those previously attended. Our guide told us that he would be quite willing to arrange visits for any small number of people, even as few as two, but he felt that half-a-day was really insufficient time, and suggested that in future a visit should cover at least a whole day. We are seriously thinking of going again ourselves to see some of the other departments and can thoroughly recommend a visit of this nature to other members of the Section.—G.H.



A model of the new Moscow Airport "Domodedowo."

THE LIBRARY

Reviews

TESTING TIME. *Constance Babington Smith. Cassell & Co. Ltd., 1961. 206 pp. Illustrated. 30s.*

" A study of man and machine in the test-flying era " is the explanatory sub-title by which the book must be both respected and judged, but Miss Babington Smith hastens in her preface to qualify the brave sweep of this promise by limiting it to the work of British pilots. If one dares thus exclude the master initiators of aeroplane test-flying, Wilbur and Orville Wright—or Voisin, Farman and Blériot—then it is safe to say that British test flying presently set the standard for the World.

Inevitably much has had to be omitted in order to compress the story into 12 very readable chapters and a mere 206 pages. Opening with a study of Dunne and proceeding to Cody, de Havilland, Roe and other early flyers, the first seven chapters are of considerable historic value. In particular, proper tribute is at last paid to Lt. Col. (later Sir) Henry Tizard, who first set the standards of orderliness and interpretation on military test-flying methods and assessment. They were re-stated and extended in Stewart Scott-Hall's and Squadron Leader T. H. England's *Aeroplane Performance Testing of 1933*, based on methods of the previous decade. There was also the test-pilot's great " bible "—Section 9 of A.P.970, detailing the full functional and flight tests mandatory for all R.A.F. and R.N. aircraft acceptance and which is still current. Had Miss Babington Smith explained this in some detail as the basis of the whole science of test flying, it could have afforded a truer picture, rather than by dealing at some length with three or four outstanding pilots as expressions of their time. The study as portrayed will give general readers the impression that between the day of Roderic Hill (with whom I would have linked his even more scientific, test flying designer brother Geoffrey) and the decade of Jeffrey Quill, there has been nothing noteworthy other than the Schneider Trophy. Yet the 20's and 30's gave no less significant contribution than today. They were times of major research into fundamentals, and the development of an enormous number of aircraft leading to contemporary practice.

Most of that arduous and dangerous experimental work was carried out by Farnborough pilots under the guidance of R.A.E. scientists—control beyond the stall, spinning, flutter, structural loading, high altitude investigation, engine behaviour, and so on. Their work is little known outside the industry.

Meanwhile the handful of industrial test pilots had a different task. At any one time there were about 25 compared with 250 today. Basically they had to make a prototype aeroplane and power plant behave within conventional and reasonable limits of mental reaction and strength before it could attempt A.P. 970 tests. What was encountered was often quite fantastic—and the process of ratification usually necessitated basic flight research similar in nature to that of the Farnborough teams. Test flying and development engineering, then as now, must be devised to overcome initial defects as simply as possible, and often as a palliative, to avoid expensive alteration and delay to components usually already in production.

Few squadrons, or airline crews, when criticising residual snags in aircraft, appreciate how nearly catastrophic these faults originally may have been. Even Martlesham of the early days, and Boscombe Down later, handled not so much the raw prototype as an expediently developed machine incorporating the minimum possible number of alterations. Always the A. & A.E.E. handling assessment, performance clearance and operational trials have been an essential and invaluable stage before an aircraft could proceed on more generalised Service trials for full clearance. It seems a pity that Miss Babington Smith did not also add the story of Martlesham and Boscombe as the sequence to Tizard's work at Upavon.

It seems a little casual of *Testing Time* to define earlier test pilots as " self taught," and add that " flight testing, as it is now called, is already radically different from test flying of the past, involving new standards and making new demands." They were always particularly able pilots, guided by aerodynamicians; and the methods used now are the logical development of those current for the last quarter of a century or more. Although we had " auto recorders " of uncertain temperament in 1930, it is in the means of recording and measuring that improvement has been greatest, though still imperfect. There are certainly more " systems " to check now, but in some ways basic problems are easier because of power controls and automatic stability equipment, instead of aerodynamic balances and inadequate blind flying aids.

In the past a number of test pilots, both service and civil, have been University Science men or have had engineering apprenticeships, but Henry Tizard and Roderic Hill were very ready to agree that such training is unimportant compared with accurate and perceptive flying, coupled with ability to diagnose and report. A test pilot is a specialist with a particular skill, who is as integrated a part of the design team as the aerodynamacist, a stressman or electronic engineer. He is their practical checker, with no need to use a slide rule.

In earlier days promising pilots with the right quality of mind and temperament—readily recognisable by another test pilot—could be guided increasingly into development test work. Each manufacturer produced a sufficient sequence of new aircraft for his pilots to progress through a wide range of testing problems; but today the development period of any one aeroplane takes so long that the effective life of a test pilot may span only a couple of prototypes. An institution such as the Empire Test Pilots' School therefore becomes necessary, where pilots can be brought to military or industrial test work with the rudiments understood, and with as wide an experience as possible of existing operational aircraft. They will still need an experienced design team to guide them.

In leaping from the early 20's to Second World War vintage I think Miss Babington Smith has done less than justice to a pilot such as Cyril Uwins, whose tremendous range of experience will never be surpassed. No man anywhere flew so many untried prototypes. His *Experimental Test Flying*, published in the Journal in 1929, was a master's exposition of the art of diagnosing and remedying cardinal faults of control and stability.

Similarly the important field of V.T.O.L. has escaped attention. There we had de la Cierva, who insisted that invention was no more than logical thinking applied first to theory and then to practice. With his Autogiros he therefore personally made each step by step air test of every major change. Like Alan Marsh, who initially tested the first British helicopters—Air Horse, Sycamore and Skeeter—Cierva played a vital part in the history of test flying, as did Shepherd and Brooke-Smith with the new epoch of jet-lift aircraft.

Nevertheless it is evident that a tremendous amount of historical research, assimilation and judicious selection has gone into the composition of *Testing Time*, emphasising the author's true understanding of the spirit of test flying. If I read the book critically, it was with unfaltering fascination at the unfolding story of a 60 year era which shows no sign of an early ending.—H. J. PENROSE.

FATE IS THE HUNTER. *Ernest K. Gann. Hodder and Stoughton, London, 1961. 352 pp. 21s.*

"Fate is the Hunter" is an autobiography, dedicated to the many friends of the author, whom Fate has hunted successfully. It is an autobiography which is unusual in that the "I"s, the "me"s and the "mine"s are so unobtrusive that they are scarcely noticeable.

Gann tells the story of himself and his friends in the world of civil aviation—the beginnings of the airlines—before and during the Second World War, and immediately after the war. It is a thrilling and enthralling tale, and the reader feels with the pilot; the heat and the cold and utter weariness; insidious fear and the exultation of achievement. This is not a dry and dusty autobiography of facts, but a graphic and gripping story of men and their deeds. It has no heroics, and yet it is full of the cold courage of both peace and war. It is difficult to single out any one episode, for the story is full of episodes, each one worthy of chronicling; the reader sweats with Gann in the Tropics and shivers in the Frozen North.

"Fate is the Hunter" has every right to stand cheek-by-jowl with such classics as "War Birds" and "One Man's War" and no doubt the sales figures will soon demonstrate its popularity.

In "Fate is the Hunter" can be read the background for some of Gann's novels, for example "The High and the Mighty" and "Island in the Sky." Assuming that Gann's novels are based on experience there are not a few instalments of Gann's life still to be written, and if these be as well written as "Fate is the Hunter" then the reading public has still something coming from the memory and pen of Ernest Gann.—A.M.B.

STUDIES OF THE HISTORY OF TERMS FOR AIRCRAFT IN ENGLISH: (TWO VOLUMES IN THE GOTHENBERG UNIVERSITY SERIES): Vol. I, Airship, Aeroplane, Aircraft; Vol. II, Balloon, Flying Machine, Helicopter. *Svante Stubelius. Almquist and Wiskell, Stockholm. 1958, 1960. 324, 396 pp. 25 Sw. kr.; 35 Sw. kr.*

On the face of it, it is hard to believe that these two volumes could be written by a human being! Never before has one man in a comparatively short space of time ever produced a work on aeronautical etymological usage and semantics. The scholarship displayed is truly prodigious; the first volume running to over 320 pages and the second to over 390.

Mr. Stubelius has combed textbooks, newspapers, fiction, reminiscences and every other kind of aeronautical literature to present us with the origins and changing definitions of the words he has chosen. I must mention some of the words he deals with, as these show what a huge field the books cover. The following are dealt with in vast detail: *aerial, air, aero, flying, aery, aeronautical, aerostatic, dirigible, airship, aerial-vessel, flying-boat, aircraft, aeroplane, airliner, jet-liner, biplane, monoplane, aviation, aviator, kite, globe, balloon, aerostat, aerodyne, navigable, balloon, flying-saucer, flying-machine, aerodrome, glider, helicopter,* and many variations and combinations of all these classes, as well as hundreds of minor words.

Having said this, and having complimented Mr. Stubelius on this most formidable and valuable achievement, it is very hard to know how a reviewer should proceed. Perhaps most readers woud like to know a few of the first usages of words they see so often; so here they are: *Aerodyne* was first suggested by Turnbull in 1906; *aeroplane*, as applied to moving surfaces, by Wenham in 1866, possibly derived from the French; for a whole fixed-wing heavier-than-air machine, the English use first appeared in 1873, derived from the changing French usage which had got under way about 1871: (*avion*, by the way, was invented by Ader about 1890-1895): *airplane* is first found in 1896; *plane*, as an abbreviation for *aeroplane*, in 1908; *aircraft*, for all types of craft, is first found in 1850, used by the American balloonist Wise, but was not common until about 1909; *biplane* was first used for a tandem monoplane in 1874, and in its modern sense in 1908; *dirigible* appeared first in 1902, derived from French usage: *soaring machine* is found in 1893; *gliding machine* in 1896; and *glider* in 1897: *monoplane* appears first in 1907: *seaplane* was invented by Sir Winston Churchill in 1913; so it goes on for these hundreds of pages, complete with literary references down to the individual page references.

I cannot help remarking on one extraordinary aspect of this subject, which is the author's Swedish nationality; it is very rare for a foreigner to master so completely the twists and turns of so many hundreds of English variants. In addition to the over 700 pages of text, there are—in the second volume—two comprehensive indices covering both; one deals with all the words covered by the volumes (amounting to over 850 words) and variants; and a general index as well to the combined work.

I feel I have done this work scant justice, but I am filled with amazement every time I use it, and I suggest that members of the Society should both inform and intimidate themselves as soon as possible by consulting the volumes in the Society's library, for a few awe-inspiring minutes.—C. H. GIBBS-SMITH.

GAS TURBINES FOR AIRCRAFT. *A. W. Judge Chapman and Hall, London, 1958. 439 pp. Illustrated. 60s.*

It is no disrespect to Mr. Judge to say that one knows more or less what to expect before one even opens a new book of his, for he is that rare bird an aero-engine journalist, who has made the semi-popular presentation of information relating to internal-combustion engines of various sorts a field perculiarly his own. The present volume is no disappointment in this respect, revealing that the author's scissors have not lost their cunning, and are more cunning than most in that one recognises substantial slabs of his previous montages of gas turbine fact and fancy.

Certainly no pains have been spared to ensure that no lecture or press release of any consequence has been overlooked. In the current phrase, the author has put "the lot" into this work, so that without neglecting Hero's "Aeolopile," without which no engine man's day is made, virtually every proposal since, whether or not it ever saw the light of day as actual hardware, has a mention, preferably *in extenso*. And not only do the complete engines and their accompanying substratum of "thermogodammits" receive thorough attention worthy of a fan club, but every related topic gets a mention somehow. Not all of these subjects is as fully documented as others, with the result that the more thinly covered of them share chapter headings in somewhat bizarre combinations such as "Augmented Power, Starting Methods" and "Failure Causes, Maintenance, Silencing, Etc."

For the man with a taste for technological history, this book constitutes a profusely illustrated source. But for the student many a word of warning is necessary, for, since the author is too generous with his information to be selective, there is more than a little danger that the student working on his own will value the bath water as lightly as the baby. He should beware of running away with the idea that heat exchange and intercooling are widely-accepted means of improving performance for aero-engines, or that high pressure ratio and the adoption of reheat or of the by-pass cycle are unimportant in this connection. Variable nozzles receive a little mention, but intakes—variable or otherwise—are ignored.

He would be a rash man who would claim to have spotted every slip or misapprehension, but it should be noted that the "most frequently employed ratio" of turbo-prop thrust (in lb.) is much more than 0·25 and 0·35 per cent of the shaft horsepower (p. 209), that equation (21) on page 409 defining compressor adiabatic efficiency has lost the inlet temperature in the numerator, and that the efficiency of a turbine is not the ratio of actual to adiabatic temperature drop, for, since the actual process is sensibly adiabatic, this ratio is always unity: it is the ratio of actual to isentropic temperature drop. In this day and

age, the young must not be treated to a confusion between the terms adiabatic and isentropic.—J. R. PALMER.

ELECTRICAL NOISE. *W. R. Bennett. McGraw-Hill, New York. 1960. 280 pp. Diagrams. 77s. 6d.*

Although a number of books on electrical noise have recently appeared, this book emphasises physical sources, experimental procedures and associated theoretical aids. Applications have a bias to communications and the author claims that the work is aimed at practising engineers with a graduate standard background.

The origin and measurement of noise in electrical circuits are described together with methods by which the effects of noise may be reduced. Qualitative analysis of the physical nature of important sources of electrical noise, such as thermal agitation, shot noise, spurious electromagnetic radiation, and gas discharges is given. Noise in semi-conductors, masers and parametric amplifiers is treated along with the better known electronic devices.

The Haus-Adler theory of noise measurement, which combines both noise figure and gain, is explained and applied to the determination of the best noise performance for a particular amplifier, in addition to the standard theory of noise figure as a basis for design.

Probably the most useful chapter to a communications engineer is the last. This deals with overall signal-to-noise ratios in complete communications systems. Various methods of amplitude modulation are examined using different forms of detector, and values for signal-to-noise ratios are evolved. Similarly, phase and frequency modulation, together with pulse code, pulse amplitude, pulse duration and pulse position modulation are analysed.

Essentially mathematical in its treatment, the book devotes a complete chapter to the application of Fourier analysis, using both series and integral methods, to the response of systems to generalised waveforms.

There is little doubt that much of the contents is of academic interest only, and some difficulty is experienced in deciding what conclusions, if any, have been reached. Despite the author's intention to present this work for the practising engineer, the reviewer doubts greatly if the book will be of interest except to a specialist in this field.

The author, now Data Communications Consultant to Bell Telephone Laboratories, has served on their staff for 35 years and is an acknowledged expert on the problems of electrical noise.—M. D. HULL.

AN INTRODUCTION TO ASTRODYNAMICS. *Robert M. L. Baker, Jr. and Maud W. Makemson. Academic Press, New York. 1960. 358 pp. $7.50.*

What is *astrodynamics*? It is a somewhat illogical term introduced recently in the United States and defined by the authors of this book in a sentence whose confused style seems to express their despair at ever finding a satisfactory definition: "*Astrodynamics* is the engineering or practical application of celestial mechanics and other allied fields such as high-altitude aerodynamics; geophysics; and electromagnetic, optimisation, observation, navigation, and propulsion theory to the contemporary problems of space vehicles."

The first chapter of the book presents some of the fundamentals of two-body orbits. The second and third chapters are brief historical surveys of the Minor Planets and Comets, which although most interesting seem rather irrelevant. Next come a key chapter on geometry and co-ordinate systems and one on fundamental constants. This concludes the more elementary part of the book, and there follow some quite advanced mathematical chapters on orbit determination and improvement, the *N*-body problem and perturbation methods. Finally, non-gravitational forces (such as radiation pressure), observation theory and navigation are discussed. After the main text come 80 further pages, containing a useful glossary, 175 references, exercises and index.

The authors show themselves well-equipped to survey the dauntingly extensive territory covered by their subject (although they are sometimes a bit shaky in their knowledge of peripheral regions), and they are to be congratulated on a book from which no persevering reader could fail to learn a great deal. Nevertheless the book cannot be wholly recommended. Despite its set of exercises at the end, it is decidedly a reference book for specialists rather than a textbook for students because it is essentially fragmentary, with the different fragments varying widely in their difficulty: some of the generalised and academic expositions of methods may repel a student from the subject for ever. The selection of references often seems perverse, because the authors rely unduly on American publications. The book is in general excellent on points of detail, but the diagrams of conics in Figs. 11 - 14 are seriously misleading, the foci being wrongly placed and a hyperbola being drawn as a semi-circle. To sum up: an important but faulty book.—D. G. KING-HELE.

PROCEEDINGS OF THE FIRST INTERNATIONAL AGRICULTURAL AVIATION CONFERENCE, 15th-18th September 1959, Cranfield. *International Agricultural Aviation Centre, The Hague, 1960. 429 pp. Illustrated. 50s.*

A list of some 250 delegates to this conference, which was held at Cranfield in September 1959, is given in the first few pages of the book and in itself forms a useful record of persons with an interest in this branch of aviation or its agricultural connotations. The great majority of delegates were, naturally, from the U.K.; about 50 people attended from countries in continental Europe and only about 10 represented areas outside Europe (including 3 from the U.S.A. and 3 from Israel). Similarly, some 40 out of the total of 50 papers which were read originated in the host country. Although this type of distribution is not abnormal for an international meeting, the Proceedings under review relate particularly to European conditions. In point of fact, this reviewer is inclined to query the title of the conference and the recent change of name from "European Agricultural Aviation Centre" to "International Agricultural Aviation Centre" unless measures are to be taken to include all countries in the membership.

Since the contents are largely European in origin, the book should be regarded as complementary to, for example, the Proceedings of the Texas Agricultural Aviation Conferences which were held a few years ago. On the other hand, many basic problems of agricultural aviation are independent of locale and a comprehensive range of subjects was covered at the conference so that, although presented as a collection of papers, the work may also be considered to constitute a useful reference textbook on the subject. In this sense, it is complementary to the *Handbook on Aerial Application in Agriculture* published in 1956 as a summation of the five Texas conferences; but is not as concise.

The promoters of the Cranfield Conference deserve recognition for the quality and the number of papers which they secured. These were presented in eleven separate sessions, within which papers were loosely allied, and the book follows the same arrangement into "sessions" or chapters for which the following general subject headings may be suggested:—the biological basis of aircraft use; materials for distribution; problems of distribution; aircraft design; distribution equipment; airworthiness regulations; corrosion; economics; hazards in spraying operations; flying techniques and safety; ground organisation. That such subject headings are not given detracts from the usefulness of the book as a reference text, as does the absence of an index; but since the work is the record of a conference, it cannot be strongly criticised on this account. If an equally large number of papers are presented at future conferences, some assistance in cross-reference would be desirable.

The technical papers are preceded by an excellent review of the history and development of agricultural aviation throughout the world (it is a pity that this includes a reference to propaganda (p. 34)—which really has no place in a scientific conference) and the organisers did well to have the very first of the technical papers deal with the biological purposes of agricultural aviation. It is also commendable that

a complete paper was allocated to invert emulsions and another to the physics of falling droplets and particles, for instance; a particularly good selection of papers is given on economics and on the design of distribution equipment, and the material contained in the book is in general most useful.

It must be mentioned that the book as a whole does suffer from minor errors and some omissions which have slipped past the proof-readers, but that the editor and his assistants have otherwise done well. When considered as the proceedings of a conference, it is noteable that very little discussion is included; this is presumably because the conference was itself remarkably poor in this important respect, and not because of inadequate reporting. When considered as a reference book, the work could have been improved by at least some indexing but will be very useful, bearing in mind the largely European approach.—P. H. SOUTHWELL.

IMPACT: The Theory and Physical Behaviour of Colliding Solids. *W. Goldsmith. Arnold, London. 1960. 379 pp. Diagrams. 90s.*

The subject of dynamic loading is one which is an old friend to the aircraft engineer. Impact loading, the subject of this book, is not such a close acquaintance for him, however. He is in the habit of treating the landing impact as a loading case, and when he performs the dynamic response calculations appropriate here, he is content with a little jugglery between normal modes and Duhamel's integral. Workers in some other fields are not able to afford to be so blasé, though, and it is for them that Professor Goldsmith had produced this encyclopaedic text.

After a short introduction, the first two main chapters are historical in that they ignore the detailed conditions at the point of contact. The author starts from the place that most of us remember from our sixth-form days—the impact of solid bodies, complete with coefficients of restitution and so on. Here, of course, the elasticity of the bodies under impact is greatly idealised. In the next chapter, the problems treated are extended to include those where the vibrations induced by the impact in the colliding bodies affect the subsequent motion. Such problems considered are the collinear impact of rods and of particles on beams, cables and columns.

The account of current theory begins in Chapter 4, in which the local deformations at contact are dealt with in detail. Various laws of contact are described and used to solve problems of impact between "solid" bodies such as spheres and also between extended bodies such as beams and plates. The following chapter is an extremely important one, covering those forms of impact which give rise to plastic strains, and follows the paths of waves of loading and unloading in rods, beams and plates, and also covers the perforation of a plate by a projectile. The last two chapters deal respectively with impact experiments and dynamic material properties, and offer a valuable account of current knowledge in these fields.

Earlier this book was described as encyclopaedic. The reference and bibliography at the end of it bear witness to this in that together they include some six hundred items. The treatment in the text is careful and exhaustive. The author's purpose is for the book "to serve as a source of reference . . . . or as a text for an advanced course in these disciplines," and he has certainly included enough material for this task. And yet the whole is not merely the sum of the parts. This reviewer found the work difficult to read. It is most inadequately sub-headed and does not follow the excellent modern practice of giving indication of chapter and section number at the head of the page. New topics are introduced in the middle of sections without even a little extra space between paragraphs.

Not many readers of this JOURNAL will want to read this book; those who do will need patience—but their patience will be rewarded.—K. H. GRIFFIN.

EMBRITTLEMENT BY LIQUID METALS. *W. Rostoker, J. M. McCaughey and H. Markus. Reinhold Publishing Corporation, New York. 1960. 162 pp. Illustrated. 64s.*

"Collects, reviews and evaluates the vast amount of information on embrittlement by liquid metals which heretofore has been scattered throughout the literature . . ." So state the words on the dustcover, and the reviewer agrees that the book is indeed informative and valuable.

The book starts with an exhaustive review of the literature on embrittlement by liquid metals and related effects. This makes somewhat tedious reading, but it is undoubtedly necessary, and will prove valuable to workers approaching the subject for the first time. Due consideration is given to the work of the Russians, and, at a later point, much of this is reviewed critically. Hereafter the book is very readable.

After dealing with the occurrence of liquid metal embrittlement, the third chapter, entitled "Crack Propagation", is principally concerned with previously unpublished work carried out by the authors and their associates. This work, which is illustrated by some excellent photographs, is largely restricted to the wetting of a particular aluminium alloy by mercury amalgams; it is a pity that more diverse examples were not available to illustrate the themes of this chapter.

Before attempting to apply dislocation theory to the subject of liquid metal embrittlement, the authors have devoted a chapter to the current ideas regarding brittle fracture. This section is quite useful in its own right as a résumé of definitions and theories (especially those of Griffith, Stroh, Cottrell and Petch). To the non-specialist reader it would provide a useful background to the mechanisms of embrittlement proposed in the final chapter. The latter begins with a restatement of the important evidence and conclusions from preceding chapters and is followed by a simple, well-reasoned attempt to explain observations in terms of established and hypothetical dislocation behaviour. It is questionable whether some of the mechanisms are important in metals, but no extravagant claims are made.

The presentation of the book is pleasing and the numerous diagrams and photographs are beyond reproach. The specialised nature of the book and the likelihood of a limited sale probably justify its price. This book would be useful to libraries and to scientists working with liquid metals and in the fields of stress corrosion and deformation.—D. J. BARBER

Additions to the Library

Basic Electronics (6 parts). van Valkenburgh, Nooger and Neville. The Technical Press, London. 1961. 111 pp., 100 pp., 92 pp., 95 pp., 112 pp., 127 pp. Illustrated. 12s. 6d. per part, 66s. per set. A revised edition of the British and Commonwealth Edition, reviewed in the November 1960 JOURNAL (p. 704) and "well recommended as providing a solid basis for more recondite studies." This basic course of instruction was originally adapted by the Electronics Team of R.E.M.E., Aborfield, from the American Edition of 1955 and is now in use also by Technical Training Command of the R.A.F., the Royal Corps of Signals and several other service units in the United Kingdom and Commonwealth.

The Conquest of Space. Albert Ducrocq. Putnam, London. 1961. 300 pp. Diagrams. 30s. *To be reviewed.*

Flexural Vibrations of Rotating Shafts. F. M. Dimentberg. Butterworths, London. 1961. 243 pp. Diagrams. 60s. *To be reviewed.*

Full Scale Fatigue Testing of Aircraft Structures. F. J. Plantema and J. Schijve (editors). Pergamon, Oxford. 1961. 426 pp. Illustrated. £5. *To be reviewed.*

Gesammelte Abhandlungen zur angewandten Mechanik, Hydro und- Aerodynamik. (Collected papers of Ludwig Prandtl). Presented by W. Tollmien, H. Schlichting, and H. Görtler. Edited by W. Riegels. Springer, Berlin. 1961. 1,608 pp. (3 volumes). Illustrated. DM 273. *To be reviewed.*

Meteorology for Glider Pilots. C. E. Wallington. John Murray, London. 1961. 284 pp. 25s. *To be reviewed.*

New Methods in Laminar Boundary-Layer Theory. D. Meksyn. Pergamon, Oxford. 1961. 294 pp. Diagrams. 70s. *To be reviewed.*

The Stability of Motion. N. G. Chetayev. Pergamon, Oxford. 1961. 200 pp. 60s. *To be reviewed.*

Unsteady Transonic Flow. Morten T. Landahl. Pergamon Oxford. 1961. 134 pp. 60s. *To be reviewed.*

Reports

NOTE—Most of the reports listed are available on loan to bonafide inquirers, but the Society is not agent for the sale of any of them. The majority are "unpublished" and are not obtainable through booksellers. Exceptions are the R. & M. and C.P. series which can be bought through Her Majesty's Stationery Office.

AERODYNAMICS

See also REFERENCE LITERATURE

BOUNDARY LAYER *see also* COMPRESSIBLE FLOW

An axially symmetric analogue for general three-dimensional boundary layers. J. C. Cooke. R. & M. 3200. 1961.—(1.1.1.2 × 1.1.3.1).

Approximate calculation of three-dimensional laminar boundary layers. J. C. Cooke. R. & M. 3201. 1961.
Three approximate methods of solving the three-dimensional laminar boundary-layer equations are tested on a problem whose exact solution is known. From the comparison, one of the methods, developed in this paper, is recommended as the one to use in general, provided that the cross-flow in the boundary layer is not large. The method is tested on two allied problems whose exact solution is known. Finally the three methods are used to find the angle between streamlines and limiting streamlines for the flow over a slender delta wing, and to determine the point of separation.—(1.1.1.1).

The determination of local turbulent skin friction from observations in the viscous sub-layer. P. Bradshaw and N. Gregory. R. & M. 3202. 1961.—(1.1.3.1).

Effects of sweep angle on the boundary-layer stability characteristics of an untapered wing at low speeds. F. W. Boltz et al. *N.A.S.A. T.N. D*-338.
Pressure-distribution and transition measurements were made at sweep angles from 0° to 50° and at angles of attack from −3° to 3°. Flow-visualisation studies on the surface and total pressure surveys in the boundary layer were also included for angles of attack from −12° to 0°.—(1.1.2.1 × 1.6.1).

Transition Reynolds numbers of separated flows at supersonic speeds. H. K. Larson and S. J. Keating. N.A.S.A. T.N. D-349. *Dec.* 1960.
Experimental research has been conducted on the effects of wall cooling, Mach number, and unit Reynolds number on the transition Reynolds number of cylindrical, separated boundary layers on an ogive-cylinder model. Results were obtained from pressure and temperature measurements and shadowgraph observations at Mach numbers between 2·06 and 4·24, Reynolds numbers (based on length of separation) between 60,000 and 400,000, and ratios of wall temperature to adiabatic wall temperature between 0·35 and 1·0.—(1.1.2.4 × 1.1.4.4).

Verallgemeinerte ähnliche Lösungen bei dreidimensionalen Grenzschichten. W. Wuest. Max-Planck-Inst. Mitt 24. 1959. *(In German).*—(1.1).

COMPRESSIBLE FLOW *see also* AIRCRAFT OPERATION
MISSILES
REFERENCE LITERATURE

Busemann correction to the characteristics of the two-dimensional hypersonic sail. E. A. Boyd. C.o.A. Report 140. *Nov.* 1960.
The two-dimensional hypersonic sail is examined using the Newton-Busemann pressure law. The results are compared with those of Daskin and Feldman (1958) who used the empirical modified Newtonian pressure law.—(1.2.3.1).

*Effect of surface roughness on characteristics of spherical shock waves. P. W. Huber and D. R. McFarland. N.A.S.A. T.R. R*23. 1959.
Measurements of peak overpressure and Mach stem height were made at four burst heights. Data were obtained with instrumentation capable of directly observing the variation of shock-wave movement with time.—(1.2.3 × 1.1.3.4).

*A supersonic area rule and an application to the design of a wing-body combination with high lift-drag ratios. R. T. Whitcomb and J. R. Sevier. N.A.S.A. T.R. R*72. 1960.—(1.2.3.1).

The numerical calculation of flow past conical bodies supporting elliptic conical shock waves at finite angles of incidence. B. R. Briggs. N.A.S.A. T.N. D-340. *Nov.* 1960.
Numerical solutions are presented for supersonic perfect-gas flow. The full inviscid equations are used and conditions at an elliptic conical shock wave are prescribed. Body shapes and surface pressure distributions are obtained. Finite angles of attack or yaw are included, and the entropy layer and singularities in the nonsymmetrical conical flow are studied.—(1.2.3.2 × 1.6.1).

The blunt plate in hypersonic flow. D. L. Baradell and M. H. Bertram. N.A.S.A. T.N. D-408. *Oct.* 1960.
The sonic-wedge characteristics method is used to investigate shock shapes and surface pressure distributions on several blunt two-dimensional shapes in a hypersonic stream. These shapes include the blunt slab aligned with the stream and at an angle of attack and power profiles of the form y proportional to x^m where $0 < m < 1$. The effects of a free-stream conical-flow gradient on the pressure distribution on a blunt slab in hypersonic flow are investigated and procedures for reducing pressure data obtained in conical flows with small gradients are presented.—(1.2.3.2 × 1.6).

CONTROLS *see* LOADS
STABILITY AND CONTROL

INTERNAL FLOW *see also* POWER PLANTS

A simplified sudden-freezing analysis for non-equilibrium nozzle flows. K. N. C. Bray. A.A.S.U. Report 161. *Dec.* 1960.
A simplified "sudden-freezing" analysis for non-equilibrium nozzle flows is used to show that the thermodynamic state of the gas after freezing is independent of the reservoir enthalpy. The flow through a given nozzle may then be represented on a single Mollier-type diagram for a wide range of reservoir conditions. Such diagrams are presented for an ideal dissociating gas and for a simple model of air.—(1.5.1).

Contribution a l'étude aérothermique d'un jet plan évoluant en présence d'une paroi. J. Mathieu. Pubs. Sc. et Tech. 374. 1961. *(In French.)*
The velocity and temperature distribution due to a hot jet striking a plane surface at various incidences is examined. In the experiment the quantities measured were: variations in temperature and velocity, correlations between normal components of velocity, spectra of velocity and temperature. The possibility of an equilibrium region similar to that asymptotic to the flow is analysed. The problem of heat transfer between jet and surface is discussed.—(1.5.1 × 1.9.1 × 34.3 × 27).

Zur Berechnung der Strömung in vielstufigen axialen Turbomaschinen mit beliebiger Beschaufelung. K. Bammert. D.F.L. Bericht 137. 1960. *(In German.)*—(1.5.3.1).

Zur Thermo-Gasdynamik der Strömung im zylindrischen Rohr. O. Lutz. D.F.L. Bericht 140. 1960. *(In German.)*—(1.5.1.1 × 1.9.1).

LOADS *see also* BOUNDARY LAYER
COMPRESSIBLE FLOW
WINGS AND AEROFOILS
METEOROLOGY
AEROELASTICITY

Effect of body-mounted lateral controls and speed brakes on the aerodynamic load distribution over a 45° swept wing at Mach numbers from 0·80 to 0·98. F. E. West. N.A.S.A. T.N. D-522. *Nov.* 1960.
The effect is shown of upper- and lower-surface body-mounted lateral controls on the wing aerodynamic load distribution at angles of attack from about 0° to 21°. These controls extended along the wing trailing edge and had a span of 0·3 of the wing semispan and a height of 0·1 of the local wing chord. The effects of control span and control hinge-line location are also shown, and the effect of speed brakes at two control deflections.—(1.6.1 × 1.3.1 × 1.3.4).

PERFORMANCE *see* STABILITY AND CONTROL
FLIGHT TESTING

STABILITY AND CONTROL *see also* WINGS AND AEROFOILS
EXTRA-ATMOSPHERIC
TECHNOLOGY
FLIGHT TESTING
MISSILES
AEROELASTICITY

Longitudinal aerodynamic characteristics of a four-propeller deflected slipstream V.T.O.L. model including the effects of ground proximity. R. E. Kuhn *and* K. J. Grunwald. *N.A.S.A. T.N. D-248. Nov.* 1960.
The transition speed range from hovering to normal flaps-retracted flight is investigated. The tests covered the effects of flap deflection, thrust coefficient, stabiliser incidence, and ground proximity. A few selected tests of the effects of thrust-line incidence, direction of inboard propeller rotation, leading-edge slat, flap-chord-extension, and tail-fan operation were included.—(1.8.2.2×3.12×1.3.4×1.3.7×29.9).

Supersonic aerodynamic characteristics of a low-drag aircraft configuration having an arrow wing of aspect ratio 1·86 *and a body of fineness ratio* 20. *W. Gillespie. N.A.S.A. T.N. D-509. Oct.* 1960.—(1.8.0.2×1.7).

Experimental investigation of some of the parameters related to the stability and control of aerial vehicles supported by ducted fans. L. P. Parlett. N.A.S.A. T.N. D-616. Nov. 1960.
Effects of ground proximity, fan-blade angle, inlet-lip radius, and inlet guide vanes have been determined for simple, lightly loaded, ducted-fan models.—(1.8.0.2×3.12).

Aerodynamic characteristics at low speed of a reentry configuration having rigid retractable conical lifting surfaces. P. G. Fournier. N.A.S.A. T.N. D-622. Nov. 1960.
Results were obtained through an angle-of-attack range from −4° to 90° on a re-entry vehicle having a rigid retractable modified conical delta wing of aspect ratio 1·2, leading-edge sweep of 73·2° and retractable tail surfaces which could be deflected from 5° to −45°. Lateral tests were made at an angle of attack of 0° through an angle-of-sideslip range of −12° to 32°.—(1.8.0.2×3.14×25.2).

An exploratory study of a parawing as a high-lift device for aircraft. R. L. Naeseth. N.A.S.A. T.N. D-629. Nov. 1960.
A wind-tunnel investigation was made of the high-lift capabilities of two supersonic aeroplane configurations equipped with parawings, which are lightweight, stowable, fabric wings of parachute-like construction used for take-off and landing.—(1.8.0.2×1.10.2.2×3).

THERMO-AERODYNAMICS *see* INTERNAL FLOW
TESTING AND INSTRUMENTS

WINGS AND AEROFOILS *see also* STABILITY AND CONTROL
AEROELASTICITY

Some observations of the flow over a delta-winged model with 55-*deg leading-edge sweep, at Mach numbers between* 0.4 *and* 1·8. *E. P. Sutton. R. & M.* 3190. 1960.
The results of lift and pitching-moment measurements at Mach numbers from 0·70 to 1·02 and from 1·42 to 1·82 are discussed with the aid of surface oil-flow observations. The Reynolds number of the tests was between 2·2 and 3·3×10⁶.—(1.10.2.2×1.8.2).

Experimental and theoretical study of a rectangular wing in a vortical wake at low speed. W. G. Smith and F. A. Lazzeroni. N.A.S.A. T.N. D-339. Oct. 1960.
Location of the vortex relative to the wing was systematically varied as well as the angle of attack of the wing. The vortex generator and wing were mounted on a reflection plane to avoid body-wing interference. A comparison is made between theory and experiment for vortex paths, induced lift, and span-wise induced load distribution.—(1.10.2.2×1.6.1×1.8.2.2).

A note on the drag due to lift of delta wings at Mach numbers up to 2·0. *R. S. Osborne and T. C. Kelly. N.A.S.A. T.N. D-545. Nov.* 1960.
Comparison of investigations of wing-body combinations employing delta wings with aspect ratios from 2 to 4 has shown that the effects on drag due to lift of Reynolds number, leading-edge radius, and thickness ratio could be correlated with Reynolds number based on the leading-edge radius as a parameter. The effects of aspect ratio, wing modifications, and trim requirements are discussed.—(1.10.2.2).

HELICOPTER AERODYNAMICS

A vibration absorber for two-bladed helicopters. Th. Laufer. N.A.S.A. T.T. F-43. Nov. 1960.
The report covers the study and use of a dynamic damper. Theoretical results and a method for calculating the horizontal damper are presented.—(1.11.1).

Hovering measurements for twin-rotor configurations with and without overlap. G. E. Sweet. N.A.S.A. T.N. D-534. 1960.
The hovering performance, including blade motions, of twin-rotor helicopters has been measured for rotors with and without overlap. These data are compared with single-rotor measurements and rotor theory.—(1.11.4).

Flight evaluation of several spring force gradients and a bob-weight in the cyclic-power-control system of a light helicopter. D. L. Mallick and J. P. Reeder. N.A.S.A. T.N. D-537. Oct. 1960.—(1.11.2).

TESTING AND INSTRUMENTS *see also* MISSILES
REFERENCE LITERATURE

The response time of wind tunnel pressure measuring systems. G. M. Lilley and D. Morton. C.o.A. Report 141. *Nov.* 1960.
The time response of a wind tunnel pressure measuring system, comprising a pressure transducer of fixed volume and a length of capillary tubing, is analysed, and the results compared with experiments.—(1.12.5).

A radiant heater to simulate aerodynamic heating in a wind tunnel. D. H. Trussell and D. J. Weidman. N.A.S.A. T.N. D-530. Nov. 1960.
A radiant-heating test technique for simulation of aerodynamic heating in a wind tunnel is described. The heating device, which utilised quartz-tube lamps, was operated successfully while exposed directly to a supersonic air stream. Tests were made on a calibration panel and experimental temperature and pressure data are presented.—(1.12.1.3×1.9.1×33.2.4.0.9).

The recording of pressure step functions of low amplitude by means of a composite-dielectric capacitance transducer placed in a parallel-T network. K. Posel. Univ. Witwatersrand. Rep. 1/61. *Jan.* 1961.
The theory is described of operation and design of a procedure to record pressure step functions (as generated by a shock tube via the amplitude modulation process of a 500 kilocycle per second carrier signal), by the capacitance change of a composite-dielectric capacitance transducer housed in a three-terminal electrical bridge configuration known as the parallel-T network.—(1.12.6.1).

A vane incidence meter for supersonic flight. J. A. Cartmel. W.R.E. Australia T.N. S.A.D. 26*th March* 1958.—(1.12.6×13).

A simple harmonic differential pressure generator. M. H. O'Donnell. W.R.E. Australia T.N. S.A.D. 51. *Jan.* 1960.
The development of a simple harmonic differential pressure generator is described, and an example given of its use in studying the frequency response characteristics of a differential pressure cone incidence meter used for flight trials. Representative results are shown for the frequency range one to four c/s.—(1.12.5×1.12.6.1).

AEROELASTICITY

See also PROPELLERS

Theoretical investigation of the subsonic and supersonic flutter characteristics of a swept wing employing a tuned sting-mass flutter suppressor. E. C. Yates. N.A.S.A. T.N. D-542. Nov. 1960.
Flutter calculations covered Mach numbers from 0 to 1·75. The flutter suppressor consists of a small mass connected to the wing by a flexible sting. This system is analogous to the spring-mass type of vibration absorber frequently used on heavy rotating machinery. Three suppressor masses were investigated but no attempt was made to make the configuration optimum. (2×1.6.3).

The effect of aeroelastic distortion on the normal force and centre of pressure of some low aspect ratio rectangular wings. W. H. Melbourne. W.R.E. Australia T.N. S.A.D. 16th Feb. 1957.
The results are given of a series of structural measurements and calculations made to estimate the normal force and centre of pressure change due to aeroelastic distortion on the wings being used in the W.R.E. wing-body programme. An empirical formula has been developed for predicting the increase of normal force due to aeroelastic distortion for a range of low aspect ratio, flat plate, rectangular wings, encastre at the root. —(2×1.10.2.2).

Aerodynamic forces on rectangular wings oscillating in subsonic flow. V. J. E. Stark. S.A.A.B. T.N. 44. *Feb.* 1960.
A numerical procedure for the calculation of aerodynamic forces at subsonic Mach numbers on oscillating wings with unswept trailing edges is described. It uses a linear approximation for the integrated acceleration potential of the reversed flow, the tangency condition of which being satisfied in the least square sense. Numerical applications are presented for 4 rectangular wings at $M=0$ and for one rectangular aspect ratio 2 wing at $M=0{\cdot}9$. Results are given for high order modes and several frequencies in both cases. Some lift distributions are shown for $A=2$ and $M=0{\cdot}9$. The forces computed for rigid modes are compared to those calculated by other theories as well as to those measured in a number of low speed tests. Applications to cropped delta wings are to follow in a later report.—(2×1.8.2.2×1.10.1.2).

AIRCRAFT

See also AERODYNAMICS—STABILITY AND CONTROL
FLIGHT TESTING
REFERENCE LITERATURE
FATIGUE

A flight study of the conversion maneuver of a tilt-duct V.T.O.L. aircraft. R. J. Tapscott and H. L. Kelley. N.A.S.A. T.N. D-372. Nov. 1960.—(3.12×13.2).

DESIGN AND CONSTRUCTION

See EXTRA-ATMOSPHERIC TECHNOLOGY
STRUCTURES—LOADS

AIRCRAFT OPERATION

See also METEOROLOGY
MISSILES

Measurements of the errors of service altimeter installations during landing-approach and take-off operations. W. Gracey et al. *N.A.S.A. T.N. D-463. Nov.* 1960.—(5.3×18×13).

Experimental and calculated flow fields produced by airplanes flying at supersonic speeds. H. J. Smith. N.A.S.A. T.N. D-621. Nov. 1960.
Pressure signatures of an F-100, an F-104, and a B-58 aeroplane, representing widely varying configurations, at distances from 120 to 425 feet from the generating aircraft and at Mach numbers from 1·2 to 1·8 are shown. Calculations using Whitham's method gave good agreement with experimental results. A procedure for calculating the $F(y)$ function used in Whitham's method is given.—(5·6×1.2.3.2).

Probleme der Höhenmessung in der Luftfahrt. H. Koppe. D.F.L. Bericht 139. 1961. *(In German).*
The necessity for obtaining accurate vertical separation of aircraft is discussed. Since barometric indication of altitude is only reliable under certain conditions and by the use of conventions, it is suggested that barometric indication of air pressure would be more satisfactory than indication of altitude. Rate-of-climb indicators are examined.—(5.3).

EXTRA-ATMOSPHERIC TECHNOLOGY

See also MATERIALS
MATHEMATICS
REFERENCE LITERATURE

First-order perturbations in the motion of earth satellites due to oblateness of the earth. V. F. Proskurin and Yu. V. Batrakov. N.A.S.A. T.T. F-45. November.
An analytical theory is presented for artificial earth satellites, on the assumption that the oblateness of the planet is small enough, so that the perturbation function in powers of the oblateness can be limited to the term containing only the first powers of the oblateness of the earth. This portion of the perturbation function is expanded in powers of the eccentricity. Integration of the ordinary Lagrange equations yields expressions of the first-order perturbations relative to the oblateness of all of the elements of the orbit, accurate to the fourth degree of the eccentricity inclusive.—(8.1×8.2).

Perturbations of orbits of artificial satellites due to air resistance. Yu. V. Batrakov and V. F. Proskurin. N.A.S.A. T.T. F-46. November 1960.
A general form of the first-order perturbations in the elements of an elliptic satellite orbit caused by the resistance of the air, is presented. It was assumed that the earth's atmosphere has a fully spherical density distribution and that the attraction of the earth can be replaced by the attraction of the material point, placed at its centre of inertia and having the same mass as the earth. These assumptions, with the secular perturbations, are used to obtain faster perturbations whose periods do not exceed the period of one rotation of the satellite.—(8.1×8.2).

Dependence of secular variations of orbit elements on the air resistance. P. E. El'yasberg. N.A.S.A. T.T. F-47. Nov. 1960.
An extension is presented of the idea, proposed by I. M. Yatsunskiy, of expanding the secular variations of the orbit elements in Bessel functions of imaginary argument. This results in simple and illustrative formulae which can be used to solve many problems, such as determination of the dependence of the secular variations of the orbit elements on the values of the elements themselves, estimation of the accuracy of determination of the air density from the measured secular variations of the orbit elements, and so on.—(8.1×8.2).

Observation of an artificial satellite by the expectation method. V. M. Vakhnin and V. V. Beletskiy. N.A.S.A. T.T. F-48. Nov. 1960.
An expectation method is presented for predicting the appearance of an artificial satellite within the observation range of the spotting equipment. For successful application, it is important to take into account only one variable factor, namely, the rate of orbit precession.—(8.2×8.1).

An approximate analytical method for studying atmosphere entry of vehicles with modulated aerodynamic forces. L. L. Levy. N.A.S.A. T.N. D-319. October 1960.
The differential equation developed in N.A.S.A. T.R. R-11 for constant aerodynamic coefficients and vehicle shapes has been modified to include entries for which the aerodynamic coefficients and vehicle shape are varied. A closed-form solution is presented for the motion, heating, and the variation of drag loading parameter m/C_DA for non-lifting entries with constant maximum resultant deceleration. Results are presented to illustrate the effects of varying m/C_DA for non-lifting entries into the earth's atmosphere at escape velocity.—(8.2×25.2).

A two-impulse plan for performing rendezvous on a once-a-day basis. J. D. Bird and D. F. Thomas. N.A.S.A. T.N. D-437. Nov. 1960.—(8.2×26).

Simulator investigation of controls and display required for terminal phase of coplanar orbital rendezvous. C. H. Wolowicz et al. *N.A.S.A. T.N. D-511. Oct.* 1960.
Two oscilloscope and one direct-visual-observation presentation and three control modes were investigated. The study was considered in terms of a manned interceptor having a home berth at a manned space station which is in circular orbit 500 miles above the earth. Interceptions were restricted to coplanar conditions.—(8.2).

Experience with a three-axis side-located controller during a static and centrifuge simulation of the piloted launch of a manned multistage vehicle. W. H. Andrews and E. C. Holleman. N.A.S.A. T.N. D-546. November 1960.
Design details of the controller, pilot opinions concerning its operation, and other data pertinent to the design and use of a controller of this type are presented.—(8.2×1.8×4.6.1).

Analysis of trajectory parameters for probe and round-trip missions to Venus. J. F. Dugan and C. R. Simsic. N.A.S.A. T.N. D-470. November 1960.
The analysis is characterised by circular coplanar planetary orbits, successive two-body approximations, impulsive velocity changes, and circular parking orbits at 1·1 planet radii. Individual velocity increments, one-way travel times, and depar-

ture dates are presented for round trips requiring the minimum total velocity increment. A set of 22 working charts for Earth-Venus trajectories may be ordered separately.—(8.2×26).

The origin of tektites. J. A. O'Keefe. N.A.S.A. T.N. D-490. November 1960.
The composition and distribution of tektites, with the fact of apparent ablation in flight, strongly suggest extra-terrestrial origin. It is shown that the ultimate source of the original tektite-producing body probably is the moon.—(8.1).

Earth shadow charts for satellite visibility prediction. J. A. B. Cartmel. W.R.E. Australia T.N. S.A.D. 28. *May* 1958.
Charts are presented giving contours of the shadow cast by the earth for heights up to 1,200 km.—(8.2×32.2.4).

Satellite attitude control using a combination of inertia wheels and a bar magnet. J. J. Adams and R. F. Brissenden. N.A.S.A. T.N. D-626. Nov. 1960.—(8.2).

AVIATION MEDICINE

Experimental electronic equipment for medical telemetry. T. Matsuo. N.A.S.A. T.T. F-51. Nov. 1960.
A report is given on a project to devise a means of observing the action of the human body at a distance by observing the small electrical voltages of the electrocardiogram, electro-encephalogram, etc., with a radio telemetry system.—(9×11).

Centrifuge study of pilot tolerance to acceleration and the effects of acceleration on pilot performance. B. Y. Creer et al. *N.A.S.A. T.N. D-337. Nov.* 1960.
The pilot performed his control tasks while being subjected to acceleration fields such as might be encountered by a forward-facing pilot flying an atmosphere entry vehicle. Information was obtained on the combined effects of complexity of control task and magnitude and direction of acceleration forces on pilot performance. Boundaries of human tolerance to acceleration were established. A comparative evaluation was made of the three-axis type of side-arm controller and the two-axis type in combination with toe pedals for yaw control.—(9).

ELECTRONICS

See also AVIATION MEDICINE
SCIENCE—GENERAL

High gain aerials. G. Callede. R.A.E. Lib. Trans. 924. *Nov.* 1960.
A study is made of high gain aerials suitable for the terrestrial end of earth-space communication systems. Expressions are given for the gain and beam-width of end-fire and aperture aerials; in particular, the circular parabolic reflector is examined. Mention is made of noise performance, and a table shows some examples of high-gain aerials which are in use for radio-astronomy and space communication.—(11).

Analysis of magnetic triodes for direct-energy conversion having flat-plate cathodes and anodes at an abitrary angle. J. E. Hatch. N.A.S.A. T.N. D-575. Nov. 1960.
A solution to the equations of motion of the electrons is found for triodes having flat-plate cathodes and anodes at an arbitrary angle and having crossed electric and magnetic fields.—(11×32.2).

Two techniques for simplifying the operation of analogue computers. L. J. Dunne. W.R.E. Australia T.N. S.A.D. 32. *July* 1958.
Two inexpensive techniques are described for simplifying the operation of analogue computers.—(11×22).

A new relay drift-corrector for use in electronic analogue computers. P. R. Benyon. W.R.E. Australia T.N. S.A.D. 34. *Sept.* 1958.
A circuit employing the usual arrangement of relay chopper, a.c. amplifier and output filter for correcting the drift of the a.c. amplifiers used in electronic analogue computers is described.—(11×22).

A single-plane trajectory computer. L. R. Henschke. W.R.E. Australia T.N. S.A.D. 35. *Dec.* 1958.
An interim version of an analogue machine for computing the trajectory in one plane of a coasting missile is described. The machine uses only standard analogue techniques and, with suitable scaling, will compute to any value of range or altitude, and to a maximum Mach number of 5.—(11×22×25.2).

A.B.A.C.U.S.—A general purpose electronic analogue computer. P. R. Benyon. W.R.E. Australia T.N. S.A.D. 49. *Oct.* 1959.
A.B.A.C.U.S. is a general purpose electronic analogue computer which will ultimately contain 72 linear computing units (adders, integrators, etc.) plus appropriate numbers of non-linear units (multipliers, function generators, etc.).—(11×22).

FLIGHT TESTING

See also AERODYNAMICS—TESTING AND INSTRUMENTS
AIRCRAFT
AIRCRAFT OPERATION
POWER PLANTS
MISSILES

Measurement of the maximum speed attained by the X-15 airplane powered with interim rocket engines. W. H. Stillwell and T. J. Larson. N.A.S.A. T.N. D-615. Sept. 1960.
On 4th August 1960 a flight was made with the X-15 aeroplane to achieve the maximum speed possible with two interim engines. The details of the techniques utilised to determine the maximum Mach number ($3{\cdot}31 \pm 0{\cdot}04$) and speed (2,196 m.p.h. ± 35) attained are presented.—(13.3×1.7×3.6).

Methods of flight testing in the Soviet Union. H. G. Schumann. AGARD Report 234. *May.* 1959.
Flight testing methods adopted in the Soviet Union are reviewed, based on data published in the Soviet Union during the last few years. Manoeuvrability and handling qualities are the subjects mainly discussed and a Table summarises the flight tests required to provide information necessary to determine the characteristics of a new design of aircraft.—(13.2×1.8).

FUELS AND LUBRICANTS

See also MATERIALS
SCIENCE—GENERAL

Lubricant behaviour in concentrated contact. The effect of temperature. F. W. Smith. N.R.C. Report M.P.-17. Aug. 1960.
Experiments are described on the frictional behaviour of a petroleum oil in the contact zone between a steel roller and an aluminium one at 23°C and between steel rollers and between tungsten carbide rollers at 23°C, 100°C and 190°C.—(14.1).

HYDRODYNAMICS

See also REFERENCE LITERATURE
STRUCTURES—THEORY AND ANALYSIS

Sur l'influence de l'accélération sur la résistance au mouvement dans les fluides. J. L. Luneau. Pubs. Sc. et. Techs. 363. 1960. (*In French.*)
The experimental study of the drag of uniformly accelerated bodies of simple geometrical shapes has confirmed the increase of drag as due to the inertia of the wake and indicates the influence of acceleration on changes in flow régime around the bodies. The drag and lift of a model of a wing in uniformly accelerated motion undergoes important modifications.—(17.1).

INSTRUMENTS AND EQUIPMENT

See also AIRCRAFT OPERATION

Low temperature performance of lead acid batteries. T. R. Ringer. N.R.C. Report M.D.-45. Sept. 1960.
The discharge characteristics of two lead acid batteries of 100- and 45-ampere-hour capacity were determined for a range of current discharge rates over a temperature range of +75°F to −60°F.—(18.1)

A photo-electric device for the measurement of quantity of liquid. R. Sandri. N.R.C. Report M.I.-822. Sept. 1960.
A photo-electric device producing an output voltage which is a linear function of the quantity of liquid contained in the measuring tube is described. A detailed description is given of the optical system, its function and possible sources of error. The method of calibration of the system is described. The apparatus can follow rapid changes of quantity of liquid.—(18.1×32.2.4).

MATERIALS

See also FATIGUE

Mechanical properties of solid and porous stainless steel sheet material at elevated temperatures. J. B. Lord. C.o.A. Note 107. *Oct.* 1960.
A series of tensile tests in the temperature range from 20°C to 1000°C were carried out on three stainless steel sheet materials, namely D.T.D. 166B, D.T.D. 171 and a woven porous material called Rigimesh. Values of Young's modulus, secant modulus, proof stress and ultimate stress were determined over the whole temperature range, values of Poisson's ratio were determined at temperatures up to 500°C. Room temperature tests were also carried out on the woven material at various orientations of the weave.—(21.2.1).

Oxidation behavior of binary niobium alloys. C. A. Barrett and J. L. Corey. N.A.S.A. T.N. D-283. *November* 1960.
A study on the oxidation resistance of 33 binary alloy systems of niobium is completed. Alloys containing up to 25 nominal atomic per cent of the alloying element were prepared by powder-metallurgy techniques and oxidised in air for 4 hours at 1000°C and 2 hours at 1200°C.—(21.2×21.4×32.1).

Halogen-containing gases as lubricants for crystallized-glass-ceramic-metal combinations at temperatures to 1500°F. *D. H. Buckley and R. L. Johnson. N.A.S.A. T.N. D*-295. *Oct.* 1960.
The gases CF_2Cl-CF_2Cl and CF_2Br-CF_2Br were used to provide lubrication for Pyroceram 9608 sliding on various nickel- and cobalt-base alloys. In the friction and wear experiments a hemispherically tipped rider (Pyroceram 9608) under a 1200-gram load slid on a disc (nickel- or cobalt-base alloy) rotating at 3200 ft./min.—(21.2×21.3.1×14.3).

Bonded and sealed external insulations for liquid-hydrogen-fuelled rocket tanks during atmospheric flight. V. H. Gray et al. *N.A.S.A. T.N. D*-476. *Oct.* 1960.
Several currently available non-metallic insulation materials that may be bonded onto liquid-hydrogen tanks and sealed against air penetration into the insulation have been investigated for application to rockets and spacecraft. Experimental data were obtained on the thermal conductivities of various materials in the cryogenic temperature range, as well as on the structural integrity and ablation characteristics of these materials at high temperatures occasioned by aerodynamic heating during atmospheric escape.—(21.3.6×21.3×27.3).

Survey of materials problems resulting from low-pressure and radiation environment in space R. A. Lad. N.A.S.A. T.N. D-477. *November* 1960.
The possible detrimental effects of the low-pressure and radiation environments on the utility of pure metals, alloys, ceramics and other inorganic compounds, plastics, and lubricants are outlined.—(21.2×21.3×14×8.2).

Thermal-fatigue crack-growth characteristics and mechanical strain cycling behavior of A-286, *Discaloy, and* 16-25-6 *austenitic steels. R. W. Smith and G. T. Smith. N.A.S.A. T.N. D*-479. *Oct.* 1960.
Thermal-fatigue crack-growth characteristics of notched and unnotched disc specimens were studied with total strain range and maximum cycle temperature independently controlled. A limited number of mechanical, push-pull, room-temperature tests made on both notched and unnotched bars revealed the effects of mean stress on the number of cycles to failure. Factors affecting fatigue life are discussed in terms of effects on the microstage and macrostage portions of crack growth.—(21.2.1×31.2.2.2.1.8×31.2.2.2.3.1.6).

On the furnace requirements for the mechanical testing of materials at elevated temperature. J. A. Dunsby. N.R.C. Report M.S.-103. *Nov.* 1960.
A review is made of the sensitivity to temperature change of the results of tensile, creep, stress rupture and fatigue tests on typical engineering metals. The temperature sensitivity is then used as the basis for an examination of the temperature tolerances specified by the existing standard codes for elevated temperature testing. Guidance is also given for tolerances for elevated temperature fatigue testing, for which no standard codes exist at present.—(21.2×31.2.2.2.2.1.8).

MATHEMATICS

See also ELECTRONICS
MISSILES

A theoretical study of the angular motions of spinning bodies in space. J. H. Suddath. N.A.S.A. T.R. R-83. 1960.
Euler's dynamic equations were linearised and solved analytically. Analytical expressions which relate angular motions to spin-rate and inertia distributions were obtained and found to be in good agreement with machine solutions of the non-linear equations for a rectangular-pulse pitching-moment disturbance. Consideration was given to the effects produced by having artificial damping in the system.—(22.2×8.2).

A modified Hansen's theory as applied to the motion of artificial satellites. P. Musen. N.A.S.A. T.N. D-492. *Nov.* 1960.
A theory is presented of oblateness perturbations of the orbits of artificial satellites based on Hansen's theory, with modification for adaptation to fast machine computation. The theory permits the easy inclusion of any gravitational terms and is suitable for the deduction of geophysical and geodetic data from orbit observations on artificial satellites. The computations can be taken to any desired order compatible with the accuracy of the geodetic papameters.—(22.3×8.2).

METEOROLOGY

A measured power spectrum of the vertical component of atmospheric turbulence. J. K. Zbrozek and D. M. Ridland. C.P. 522. 1960.
Aircraft response to turbulent air is studied using power spectrum methods. Consideration is given to the spectral technique as applied to measurements of atmospheric turbulence and a number of theoretical relationships are quoted. The spectrum of the gust vertical velocity component obtained from the first sample of turbulence analysed is discussed.—(24×1.6.3×5.3).

Atmospheric turbulence measurements obtained from airplane operations at altitudes between 20,000 *and* 75,000 *feet for several areas in the Northern Hemisphere. T. L. Coleman and R. Steiner. N.A.S.A. T.N. D*-548. *Oct.* 1960.
An analysis is given of data on atmospheric turbulence obtained from *VGH* records taken on Lockheed U-2 aeroplanes. The flights covered approximately 315,000 miles over several areas of the Northern Hemisphere and consisted of five separate samples. The gust experience for the five samples is determined and the variation in the gust frequencies and the percentage of flight distance in rough air with altitude are indicated. These results are compared with previous estimates and information on the length of turbulent areas is also given.—(24×5.3×1.6.3).

Idealized wind profiles applicable for the study of vehicle performance between 60 *K.M. and* 80 *K.M. altitude Cape Canaveral (Atlantic Missile Range), Florida. W. W. Vaughan. N.A.S.A. T.N. D*-560. *Dec.* 1960.—(24).

The development of a vapour trail technique for the determination of wind patterns at low altitude. T. H. Cooke. W.R.E. Australia T.N. S.A.D. 29. *May* 1958.
In firing the Skylark upper atmosphere sounding rocket a knowledge of low altitude winds before and during firing is necessary. Existing meteorological methods are inadequate and the vapour trail technique has been developed to augment these. Investigation of wind gust structure should be possible using the trail laid by these vehicles.—(24×13).

MISSILES

See also AERODYNAMICS—STABILITY AND CONTROL
EXTRA-ATMOSPHERIC TECHNOLOGY
ELECTRONICS
POWER PLANTS
REFERENCE LITERATURE

A self-adaptive missile guidance system for statistical inputs. H. R. Peery. N.A.S.A. T.N. D-343. *Nov.* 1960.
Newton's modified Wiener theory is utilised in the design of the system and to establish the performance criterion. The missile is assumed to be a beam rider, to have a *g* limiter, and to operate over a flight envelope where the open-loop gain varies by a factor of 20.—(25.1).

Measured base pressures on several twin rocket-nozzle configurations at Mach numbers of 0·6 to 1·4 with effects due to nozzle canting and stabilizing fins. J. M. Cubbage and E. H. Andrews. N.A.S.A. T.N. D-544. Nov. 1960.
An investigation to determine base pressures on several cylindrical afterbody configurations is reported. Nozzles with design Mach numbers of 2·0 and 3·43 were operated over a nozzle pressure ratio range of 1 to 120 using cold air to simulate nozzle flow.—(25.2×27.3×1.2.3).

The expected errors of a least squares solution of location from direction-finding equipment. B. Harkin. W.R.E. Australia T.N. S.A.D. 2. *October* 1955.
Formulae are derived for the error variances and covariances of the co-ordinate components of an unweighted least squares solution for location of a missile simultaneously reported by a number of finding stations, optical or electronic. Practical applications of the formulae are projected.—(25.1×22.1).

A note on the present state of development of a method of airborne recovery of missiles. W. T. S. Pearson. W.R.E. Australia T.N. S.A.D. 6. *Nov.* 1956.
Earlier proposals to prevent damage to missiles on impact with the ground by intercepting them in the air with an aircraft are re-stated in the light of exploratory trials. The problem of interception is broken down into some detail and one solution outlined, together with a brief description of an interception sight now in use. The development of a paravane capable of supporting a sweep cable (fitted with grappling hooks) to one side of the aircraft is recorded and the design of a ground rig which can accept a captured missile from its position on tow behind the aircraft is given. Assessments of the economics and the limitations of the system are attempted.—(25).

The magnitude of the roll error resulting from missile manoeuvre. B. Harkin. W.R.E. Australia T.N. S.A.D. 4. *Oct.* 1955.
For both simultaneous and successive pitch and yaw deflection of a roll-stabilised missile, the kinematic effect upon the roll position is formulated, evaluated and graphically illustrated.—(25.1×22.3×1.8.1.1).

The effect of rolling during boost on the dispersion at separation of RTV1e. P. M. Twiss. W.R.E. Australia T.N. S.A.D. 7. *July* 1956.
Values of the dispersion at separation of RTV1e are analysed to determine the reduction in dispersion which could be achieved by the use of a suitable spin form during boost.—(25.2).

The development of an aircraft-towed paravane. W. T. Pearson and T. N. Pound. W.R.E. Australia T.N. S.A.D. 10. *Sept.* 1956.
The problems encountered in achieving adequate performance and stability on tow are outlined and launching difficulties described. The results of wind tunnel model tests and full scale flight trials are summarised.—(25).

An airborne balance for measuring drag of missile components description and results of proving trials. D. G. Strahle. W.R.E. Australia T.N. S.A.D. 13. *August* 1956.
An airborne balance for measuring the drag of missile components such as aerials, fairings, fins and small wings, is described. The results are given of four proving trials in which the drags of a circular and a double-wedge aerial were measured, and it is shown that there is reasonably good agreement with the results of the other investigations.—(25.2×1.12.2).

Flight measurements of mechanical vibration and sound levels in a motored RTV1. D. G. Strahle and M. A. Powell. W.R.E. Australia T.N. S.A.D. 14. *Sept* 1956.—(25×13×5.6×1.12.6).

The design, development and model tests of the Mk. II aircraft towed paravane. W. H. Melbourne. W.R.E. Australia. T.N. S.A.D. 17. *February* 1957.
The development of an aircraft towed paravane which will support a steel cable to one side of an aircraft, for use in the airborne recovery of missiles is described. Results are presented of an investigation, using a free flight model, into the effect of two important derivatives on paravane stability, and of preliminary full scale flight trials. Details of recent modifications to the Mk. I paravane are listed.—(25×1.8.1.2).

The expected error of a weighted least squares solution of location from direction finding equipment. B. Harkin. W.R.E. Australia T.N. S.A.D. 33. *Sept.* 1958.
Formulae are established for the co-ordinate component error variances and co-variances of a weighted least squares solution of location from a number of direction-finding instruments. Some examples illustrate the application of the formulae to siting problems.—(25.1×22.1).

Performance characteristics of the two stage rocket Aeolus. R. A. Bissell. W.R.E. Australia T.N. S.A.D. 38. *April* 1959.
—(25.3).

Airborne recovery of guided missiles: results of the first successful interception trial. D. Barnsley. W.R.E. Australia T.N. S.A.D. 19. *April* 1957.
An account is given of the first successful interception of a ground launched test vehicle by an aircraft, in the programme to develop a system of airborne recovery of missiles.—(25).

A method for the determination of missile attitude using ground cameras. J. A. B. Cartmel. W.R.E. Australia T.N. S.A.D. 20. *July* 1957.
Consideration is given to the layout of a number of individual cameras where adequate coverage throughout the whole flight may not be obtained with one camera An example of the application of the method is given.—(25×5.5).

The effect of roll rate on some dynamic properties of a symmetrical missile. B. A. M. Moon. W.R.E. Australia T.N. S.A.D. 25. *November* 1957.
A complex variable method is applied to some problems of a rolling missile. This simplifies the dynamic equations and makes more apparent the effect of roll on the behaviour of the system.—(25.2×1.8.1.1).

Generalised co-ordinate ISACRIBS of instrumental triangulation. B. Harkin. W.R.E. Australia T.N. S.A.D. 54. *Feb.* 1960.
For a Cartesian co-ordinate system based symmetrically upon the siting of two direction-finding instruments employed to locate a missile, equipotential surfaces of co-ordinate component error are represented isometrically and also by means of error contours drawn for selected planes of section. The error levels illustrated are specific to the M.T.S. system, but by appropriate scaling, the figures are applicable to any direction-finding system, optical or electronic.—(25).

NAVIGATION

See EXTRA-ATMOSPHERIC TECHNOLOGY
REFERENCE LITERATURE

POWER PLANTS

See also AERODYNAMICS—INTERNAL FLOW
MATERIALS
MISSILES
REFERENCE LITERATURE
SCIENCE—GENERAL

Performance of several method-of-characteristics exhaust nozzles. J. M. Farley and C. E. Campbell. N.A.S.A. T.N. D-293. Oct. 1960.
Nozzle performance data were obtained with three "method-of-characteristics" nozzles and a 15° conical nozzle at pressure ratios up to 130. Each basic configuration was cut off and tested at expansion ratios of 25, 20, 15 and 10.—(27.3.1×1.5).

Flight performance of a spin-stabilized 20-inch-diameter solid-propellant spherical rocket motor. J. Levine et al. *N.A.S.A. T.N. D-441. Sept.* 1960.
The motor was fired at altitude after being boosted by a three-stage test vehicle. The results are shown to be in excellent agreement with data from ground static firing tests of these motors.—(27.3.2×25.3×13.3).

Analytical investigation of cycle characteristics for advanced turboelectric space power systems. T. P. Moffitt and F. W. Klag. N.A.S.A. T.N. D-472. Oct. 1960.
An investigation was made of the relative influence of turbine inlet temperature, radiator temperature, and turbine efficiency on required radiator area for Rankine cycles and rubidium, potassium, and sodium as working fluids. A further analysis was made of the factors influencing turbine efficiency and design for alkali-metal applications. The effect of working fluid and rotor speed on required number of stages and the effect of moisture on efficiency are considered. Methods of reducing moisture content are compared.—(27.6×27.7).

An analytical investigation of three general methods of calculating chemical-equilibrium compositions. F. J. Zeleznik and S. Gordon. N.A.S.A. T.N. D-473. Sept. 1960.—(27.3×32.1).

Effect of propellant and catalyst bed temperatures on thrust buildup in several hydrogen peroxide reaction control rockets. J. P. Wanhainen et al. *N.A.S.A. T.N. D-480. Oct.* 1960.
The starting characteristics of several representative commercial production samples of 90 per cent hydrogen peroxide attitude control thrust chambers were determined. Start delay times are presented for a range of chamber and propellant feed temperatures from approximately 30° to 100°F.—(27.3).

An analysis of nuclear-rocket nozzle cooling. W. H. Robbins et al. *N.A.S.A. T.N. D-482. Nov.* 1960.
A nuclear-rocket regenerative-cooling analysis was conducted over a range of reactor power of 46 to 1600 megawatts. Techniques for improving the cooling margin were discussed, e.g., high pressure drop, high wall temperature, refractory wall coatings, thin highly conductive walls, film cooling.—(27.6×34.3.4).

Effect of base bleed and terminal fairings on the performance of exhaust-nozzle-afterbody combinations at Mach numbers of 1·93, 2·55 *and* 3·05. *H. T. Norton and A. L. Keith. N.A.S.A. T.N. D-539. Nov.* 1960.—(27.1.1.1).

Gedanken über ein Triebwerk für Schul-und Sportflugzeuge. K. Löhner. D.F.L. Bericht 124. 1960. *(In German.)*—(27.2).

Konzentrische Rohre als Treibsatzform für Feststoffraketen. O. Lutz et al. *D.F.L. Bericht* 132. 1960. *(In German.)*—(27.3).

PROPELLERS

See also AERODYNAMICS—STABILITY AND CONTROL

The torsional oscillations of airscrew blades at low mean incidences. J. P. Jones. R. & M. 3177. 1960.—(29.1×2).

Air circulator fans: a design method and experimental studies. V. J. Smith. A.R.L. Report A 119. *April* 1960.—(29.8×29.1).

Wind tunnel and static thrust measurements on a four-blade constant chord propeller. R. H. Wickens. N.R.C. Report L.R.-291. *Oct.* 1960.—(29.1×29.6×29.7).

REFERENCE LITERATURE

Systems of co-ordinates and basic symbols used for aerodynamic and hydrodynamic calculations in aircraft construction. S.S.S.R. Government Standard. R.A.E. Lib. Trans. 928. *Dec.* 1960. —(30×1.0×17.0).

Decennial Symposium. Technical Sessions VTOL/STOL I. VTOL/STOL II. U.T.I.A. Procs. Part II. 14th-16th *Oct.* 1959.
The jet flap is briefly reviewed. Its principle is defined and its outstanding virtues—as *e.g.* summarised in the thrust and lift hypotheses—are discussed and analysed as to their aerodynamic background. Next the proper jet is compared with the jet augmented flap. The most useful and practical theoretical jet flap theories are briefly covered and the total and induced jet flap drag is discussed. Finally the jet flap features are evaluated as to their usefulness to all types of jet engine powered aircraft, especially for STOL.—(30.2×3.12).

Decennial Symposium. Technical Sessions. Gasdynamics Astronautics. I, Astronautics II. U.T.I.A. Procs. Part III. 14th-16th *Oct.* 1959.—(30.2×8.2×1.12.1.3×1.2.3.2×25.1×26×27.7).

FATIGUE

See also MATERIALS

Fatigue loadings in flight-loads in the nose undercarriage and wing of a Valiant. E. W. Wells. C.P. 521. 1960.
Data obtained on the number of load cycles of various magnitudes occurring in the wing and the nose undercarriage of a Valiant in normal ground and flight conditions are presented. —(31.2.4.5×31.2.4.2×33.1.1×3.6).

Prediction of unstable crack length in aluminium alloys. R. H. Ryder. C.o.A. Note 109. *Oct.* 1960.
A method was set down for predicting the unstable length of a crack in a flat sheet of aluminium alloy subjected to a steady tensile stress. The basis of the method was to take the work done to failure in the "neck" region of a tensile test specimen and apply it, with a suitable constraint factor, to the flat sheet to give the work rate required to propagate the crack. Experimental evidence is produced in support of the method.—(31.2.2.3.2.1.6×21.2.2).

Fatigue investigation of full-scale transport-airplane wings: Tests with constant-amplitude and variable-amplitude loading schedules. L. R. Foster and R. E. Whaley. N.A.S.A. T.N. D-547. Oct. 1960.
Six fatigue tests were conducted on C-46 aeroplane wings: two tests at a high constant-amplitude load, two with loading schedules based on gust-frequency statistics, and two with loading schedules developed from manoeuvre-loads statistics. The results are compared with previously published data from other tests in this series.—(31.2.4.2×3.6).

Fatigue damage under varying stress amplitudes. H. W. Liu and H. T. Corten. N.A.S.A. T.N. D-647. Nov. 1960.
The influence of complex stress histories on the fatigue life of members was investigated to determine the relationship between fatigue life and the relative number and amplitude of imposed cycles of stress.—(31.2.2.2.2.1.1×31.2.2.3.2.1.1×21.2).

Fatigue problems associated with structural materials for current and future aircraft. J. Y. Mann. A.R.L. Report S.M. 270. *Sept.* 1960.
The fatigue properties of alloys of aluminium, magnesium and titanium, and plastics used in the structures of current aircraft are discussed with particular reference to stress concentrations, sub-zero temperatures and corrosive conditions. A review is made of the fatigue behaviour of currently used structural materials at elevated temperatures and of the fatigue behaviour of alloys developed specifically for use under such conditions. Also included are potential elevated temperature materials such as special steels, glasses and ceramics. Brief reference is made to new production methods and processes.—(31.2.2.1×21.2).

Size effects on fatigue crack initiation and propagation in aluminium sheet specimens subjected to stresses of nearly constant amplitude. W. Weibull. F.F.A. Report 86. 1960.
Fatigue tests on axially-loaded 24S-T and 75S-T aluminium sheet specimens of various sizes were conducted with a constant nominal stress amplitude, established by a stepwise reduction of the load in proportion to the remaining cross-sectional area. —(31.2.2.3.2.1.1×21.2.2).

Untersuchungen über statische Langzeit und dynamische Dauerfestigkeit von glasfaserverstärkten ungesättigten Polyester-Laminaten G. Niederstadt. D.F.L. Bericht 141. 1960. *(In German.)*—(31.2.2.9.2.1×21.3.3).

SCIENCE—GENERAL

See also EXTRA-ATMOSPHERIC TECHNOLOGY
ELECTRONICS
INSTRUMENTS AND EQUIPMENT
MATERIALS
POWER PLANTS

Load compensation techniques using multi-tapped potentiometers. K. C. Garner. C.o.A. Note 108. *December* 1960.
The theory is developed for loading error compensation techniques utilising multi-tapped potentiometers. Two methods of compensation are derived and their relative advantages discussed. Design formulae are given for calculating appropriate values of the shunt resistors to be used with the tapped potentiometers. (Numerical examples of each method are given.—(32.2.1).

Present-day ideas concerning the mechanism of electrical breakdown in high vacuum. L. V. Tarasova. N.A.S.A. T.T. F-42. Oct. 1960.
The nature of electrical breakdown is investigated for the case of very high vacuum and potentials. Breakdown potentials and side effects are discussed for various conditions, and theoretical explanations are considered. Included are cases involving breakdown across the surface of dielectrics.—(32.2× 27.7×11×14).

A thermistor pressure gauge. A. P. Flanick and J. Ainsworth. N.A.S.A. T.N. D-504. Nov. 1960.
Design procedures for a thermistor pressure gauge are presented. A method was devised and equipment was constructed for rapid and accurate pressure-gauge calibration.—(32.2).